ADC626979

AMRL-TR-65-65

MOBILITY OF PRESSURE-SUITED SUBJECTS UNDER WEIGHTLESS AND LUNAR GRAVITY CONDITIONS

JOHN C. SIMONS, MAJOR, USAF

DIETER E. WALK

CHARLES W. SEARS, M/SERGEANT, USAF

AUGUST 1965

20040507008

AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

800 - January 1966 - 24-470-773

MOBILITY OF PRESSURE-SUITED SUBJECTS UNDER WEIGHTLESS AND LUNAR GRAVITY CONDITIONS

JOHN C. SIMONS, MAJOR, USAF

DIETER E. WALK

CHARLES W. SEARS, M/SERGEANT, USAF

FOREWORD

This report was prepared by the Crew Stations and Anthropology Branches of the Human Engineering Division, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, under Project No. 7184, "Human Performance in Advanced Systems", and Task Nos. 718405, "Design Criteria for Crew Stations in Advanced Systems", and 718408, "Anthropology for Design".

Acknowledgement is made to Mr. Tim Sweeney and Mr. Philip Kulwicki for their geometrical analyses of various exit shape, size and area relationships; to Mr. Jack Morga, of Headquarters, Air Force Logistics Command, for the design of the adjustable iris; to Mr. Anthony Grandillo and Mr. William Brockman of the Research Institute, University of Dayton, for their assistance with the analyses of variance and photo data reduction; and to Mr. Kenneth Kennedy of the Aerospace Medical Research Laboratories for the data on reach envelopes for 2.5 and 3.5 psi pressure suit inflation levels.

Acknowledgement is also made to Dr. M. J. Warrick and Dr. D. F. Kasten, both of the Aerospace Medical Research Laboratories, for their assistance in organizing and integrating the various contributions to this report.

This study reports the first lunar gravity research flown in the United States and special acknowledgement is due Major Edwin J. Hatzenbuehler, test pilot, Aeronautical Systems Division, for his assistance in developing, flying, and directing the lunar gravity flights. The effort reported herein was started in June 1961, completed in June 1962.

This technical report has been reviewed and is approved.

WALTER F. GRETHER, PhD
Technical Director
Behavioral Sciences Laboratory
Aerospace Medical Research
Laboratories

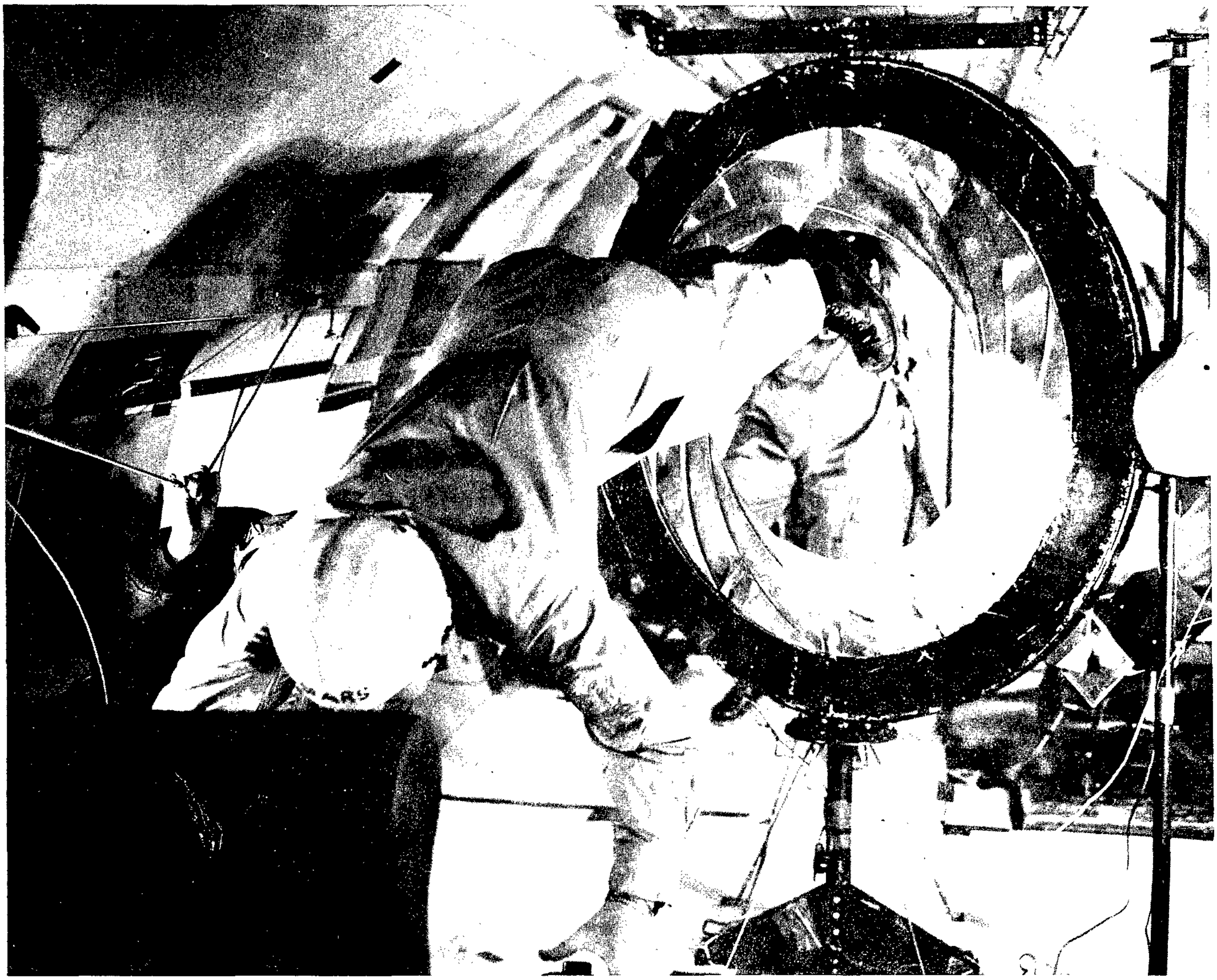
ABSTRACT

Problems of moving through hatchways under zero and lunar gravity conditions, and related design problems of hatch size and shape, were investigated inflight. Subjects were timed and photographed as they accomplished various motions during weightless and lunar-gravity maneuvers of a large cabin aircraft. Performance data are presented for various combinations of clothing, gravity and body-position conditions. Time and contact data are presented for the egress motion as it is influenced by changes in the exit area. Orientation problems and maneuvering techniques, as influenced by area and volume restrictions, are discussed. Motions of pressure-suited subjects generally required 30% more time than corresponding motions of unsuited subjects. Most motions required 35% more time during zero G than during lunar G. No significant differences in egress times were found among four body-positions. Compared with 1 inch of exit clearance, 5 inches of clearance improved egress time by approximately 6%. Accuracy, rather than time of motion, appeared to be a more sensitive measure of operator performance for the egress task. A 95th percentile shoulder plane with a 19.4-inch major axis is proposed as a basic egress reference.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)



Preceding Page Blank

MOBILITY OF PRESSURE-SUITED SUBJECTS UNDER WEIGHTLESS AND LUNAR GRAVITY CONDITIONS

John C. Simons, Major, USAF

Dieter E. Walk

Charles W. Sears, M/Sergeant, USAF

SECTION I

INTRODUCTION

Hammer (ref 1) describes the motion behavior of the free-floating shirt-sleeved operator. The description of motion behavior is herein extended to include inflated full-pressure suit and lunar-gravity conditions. The RESULTS section describes, in summary form, the motion behavior of pressure-suited subjects while lunging, egressing and landing under zero and lunar gravity conditions. Quantitative analyses of the subject's motions and of factors that influence them are presented. The subject's comments are categorized and are included to illustrate orientation problems and to suggest hardware designs for improving performance.

SECTION II

METHOD

Lunging, egressing (see frontispiece), and landing tasks were structured by having the subjects travel the route shown in figure 1: depart seat No. 1, egress through an adjustable iris, and arrive at and position themselves in seat No. 2 in a zero-G aircraft.

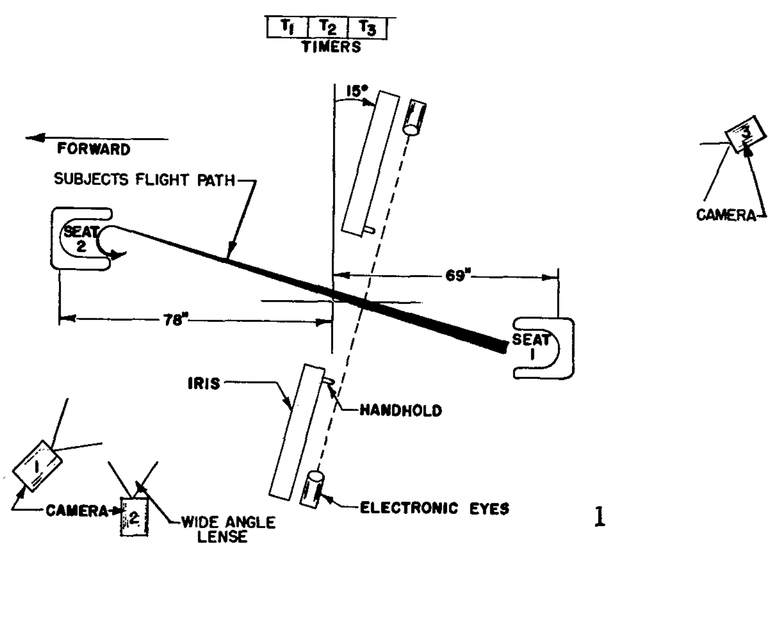


Figure 1

Test Area in Zero-G Air-Craft

APPARATUS

A circular aluminum iris (figure 2) was mounted in the aft cabin area of the C-131B aircraft. The iris could be adjusted, with a hand lever, from 19 to 40 inches in diameter by 1/2-inch increments. The extensive experimental design and the limited availablity of aircraft time precluded the use of more than one iris shape.

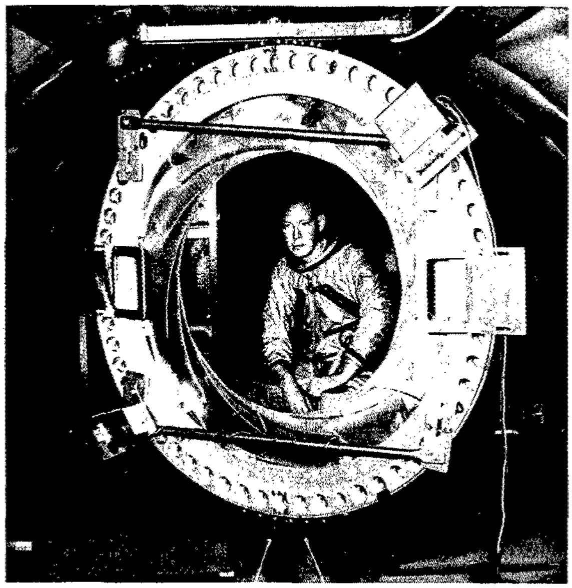


Figure 2. Adjustable Iris, Fixed Handholds, and Photo Cells

The following objective and subjective records were taken:

a. 16mm movies of all trials with camera No. 1 (see figure 1) covering the egress and landing area, camera No. 2 covering the landing area camera No. 3 covering the lunging and ingress area. The films were used to analyze maneuvering techniques, handhold usage, and body contacts and to doublecheck the sequence of condition presentations.

b. Time from seat No. 1 (see figure 1) to the iris (T-1, lunge time), through the iris (T-2, egress time), and from the iris to seat No. 2 (T-3, landing time). The lunging-time period included the tasks of departure (reaction time), standing, walking, grasping, and pulling. The landing-time period included tasks of soaring, grasping, holding, turning, and sitting. Lunge time was the time interval between the hand release of a pressure switch in seat No. 1 and the body's interruption of the photo cell beam at the iris. Egress time was the duration of interruption of the photocell beam (see figure 1). Landing time was the interval from egress to body contact on a pressure switch mounted in seat No. 2.

To minimize motion sickness probabilities and apprehension over in-flight problems, only subjects with zero-G experience and complete familiarity with the wearing of the full-pressure suit were selected. For the unsuited

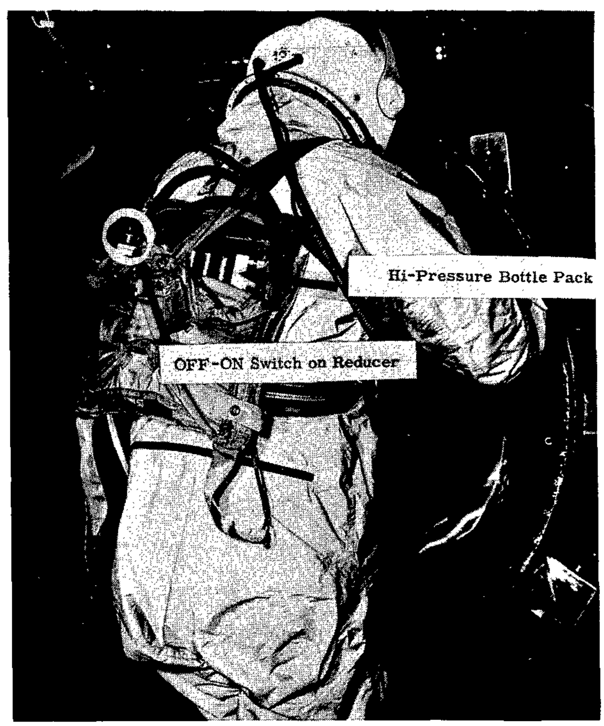
trials, the subjects wore regulation summer flying suits and a soft safety helmet. For the pressure-suited trials, they wore the A/P-22S-2 full-pressure suit which was designed for an operational inflation level of 3-1/2 psi. (This pressure level is now being considered for future space requirements, with a safety factor of inflation to 5 psi in case of abnormal occurrences, such as bends, etc.) In our tests, a pressure level of 2 1/2 psi was maintained by a press-to-test feature (figure 3). Valves allowed an inflation pressure of 2-1/2 psi and dumped any added pressure which was supplied. (Subject motion capability under 3-1/2- and 2-1/2-psi inflation is presented in appendix IV.)

A portable, air supply inflation unit (figure 3) was worn by the subjects to free them from aircraft-connected lines or hose and to allow them to maneuver and soar freely. The air supply unit provided a 4-minute supply of air for breathing and for inflating the suit. A shutoff switch on the air bottles conserved the air supply between parabolas. Figure 3 shows the integration of the high-pressure bottles and the A/P-22S-2 full-pressure suit.

EXPERIMENTAL DESIGN

Each of 10 subjects was given 48 trials during 2 flights (forming the "without-replication" group). Three subjects were rerun to study learning and fatigue effects ("with-replication" group). The experimental variables were selected after a pilot study involving three of the subjects (appendix I).

A. Front View



B. Rear View

Figure 3. Portable Air Supply Inflation Unit

Table 1 lists the time scores and presentation of conditions. The experiment was a fixed factorial design with 4 treatments (gravity, clothing, iris clearance, and body position for approach to iris) and 13 orders of presentation. Subjects and presentation order were confounded. The treatment levels were presented in a partially counterbalanced order.

The unsuited shoulder width of all subjects was measured directly (see appendix VI for subjects, anthropometrics). Two inches were added to this dimension to obtain shoulder width for the suited condition. Iris diameters were equated by adjusting the iris for each trial to each subject's shoulder width plus clearance. Clothing levels were only partially counterbalanced, because of the subject's inability to don a pressure rapidly between trials.

Film from cameras Nos. 1, 2, and 3 were projected in slow motion for two film editors who independently tallied handhold usage and all discernible touches (contacts) the subjects made with the iris. A third editor resolved disagreement about contact occurrences. Data cards were punched for subjects' trials with the following coded bits of information:

Test Date
Trial No. (1 to 24)
Subject (1 to 13)
Clothing (coverall or pressure suit inflated 2-1/2 psi)
Gravity (zero-G or lunar-G)
Iris Clearance, (+1-, +5-, or +10-inch)
Body-Handhold Position (headfirst-side; headfirst-bottom; feetfirst-side; feetfirst-top)
Hangup (Subject's progress stopped)
Body Contacts (including head, shoulder, arm, hand, back, butt, hip, upper leg, stomach, knee, calf, skin, ankle, heel, sole or toe, also left, right or both for limbs)

No attempt was made to separate purposeful from inadvertent contacts. The subjects were instructed to use the handholds and not the iris as the primary source of propulsion. Time scores were separately recorded and permitted a comparison of main effects and first order interactions. An analysis of contact scores permitted time-accuracy comparisons.

To isolate the motions used by the subject in the landing phase, two planes were assigned to his body, eg, the anterior chest and face plane. Film from camera No. 1 was analyzed to determine in which order and through how many planes to two imaginary blocks (one shown in figure 4) the subject passed.

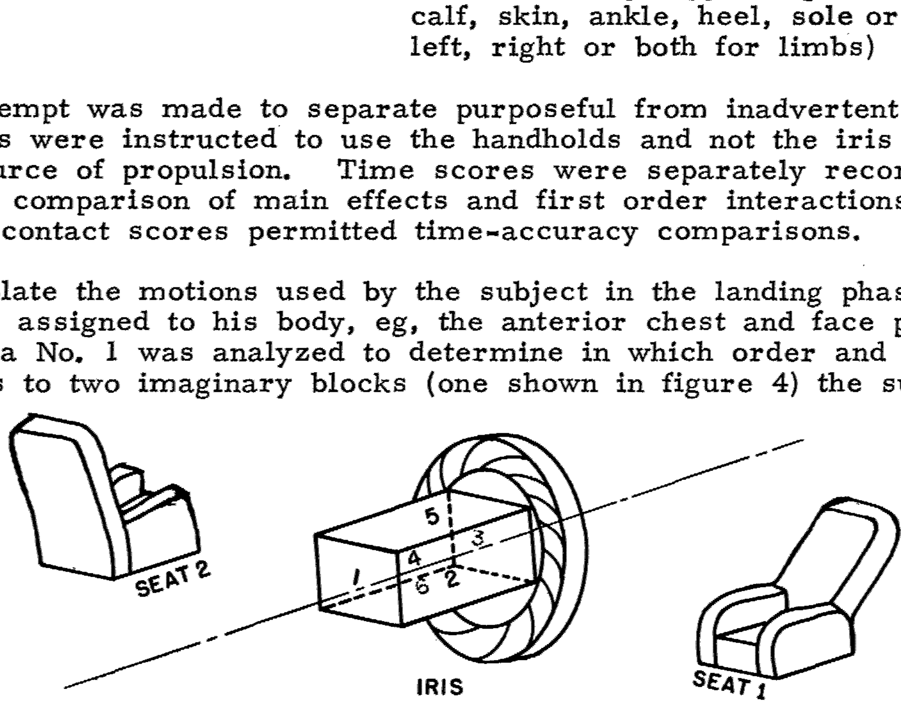


Figure 4. Imaginary Six Body Planes

TABLE I*
TIME SCORES T1, T2, T3
COUNTERBALANCED ORDER OF PRESENTATION OF EACH TREATMENT
(Time in Seconds)

		1	2	3	4	5	6	7	8	9	10	11	12
SUBJECT 1		G2L2P2	G1L3P4	G1L3P2	G2L2P3	G1L2P1	G1L1P3	G2L1P2	G1L2P4	G1L1P2	G2L3P1	G1L1P1	G2L3P3
	C1	1.38	1.39	1.92	1.97	1.84	2.66	1.63	0.89	0.98	0.41	0.68	1.89
		1.39	1.25	1.09	0.81	1.30	1.36	1.67	1.08	0.94	1.71	2.59	0.37
		1.69	5.41	5.24	2.60	8.33	5.61	5.02	5.05	5.22	2.68	2.81	3.34
		G1L3P2	G2L3P4	G1L3P3	G1L1P3	G1L3P4	G2L3P1	G2L2P4	G1L2P2	G1L2P4	G2L2P2	G1L2P3	G1L1P2
	C2	1.60	1.33		2.32	1.46	2.52		1.44	1.67	1.41	2.65	1.98
		1.86	1.58	0.89	1.27	1.16	0.91	1.48	1.80	0.89	1.05	1.10	2.20
		5.53	6.58	8.49	5.69	3.89	2.65	1.75	3.10	7.01	1.35	5.92	5.16
SUBJECT 2		G1L1P1	G1L3P2	G1L2P4	G1L3P4	G2L3P2	G1L2P3	G2L2P1	G1L1P3	G2L2P2	G1L1P2	G1L2P1	G2L1P1
	C2	2.11	0.87	2.01	1.71	1.17	2.10	1.06	6.18	0.66	0.96	0.76	0.60
		1.99	1.08	1.34	1.23	0.56	1.54	0.99	4.17	1.41	1.22	1.28	1.25
		5.49	2.29	4.73	9.59	2.15	4.25	2.11	4.92	3.43	3.28	4.10	2.12
	C1	G2L1P3	G2L3P4	G1L3P3	G2L1P2	G1L3P1	G2L2P1	G1L1P2	G1L3P4	G1L1P1	G1L1P4	G2L3P1	G2L2P4
		1.06	0.78	0.91	0.64	0.54	0.62	0.81	0.83	0.83	0.50	0.69	0.70
		0.70	0.63	0.74	0.62	0.75	0.83	0.50	0.60	1.05	0.93	0.61	0.79
		2.06	2.42	3.30	2.02	4.80	2.52	3.38	4.23	6.83	2.32	3.00	1.54
SUBJECT 3		G2L2P1	G2L3P1	G2L1P1	G2L1P3	G2L2P3	G1L1P4	G2L1P4	G2L2P2	G2L3P3	G1L3P2	G1L1P1	G1L3P4
	C1	0.91	0.84	0.79	0.95	0.82	0.88	0.86	0.51	0.71	0.65	0.60	0.82
		1.43	0.66	1.60	1.53	1.19	1.23	1.21	1.08	0.93	0.82	2.55	0.81
		1.77	2.40	1.16	1.94	1.57	3.56	1.26	1.06	1.32	3.08	2.62	2.06
		G2L3P2	G2L2P4	G1L3P3	G1L2P1	G1L2P4	G1L1P4	G2L1P3	G1L2P2	G2L2P2	G2L1P1	G1L1P2	G1L2P3
	C2	1.34	1.36	0.97	0.99	2.03	1.27	1.28	1.13	0.65	2.58	0.60	1.23
		0.47	0.62	0.66	2.12	0.87	1.29	3.44	1.11	0.74	0.21	1.30	1.24
		1.98	1.03	3.71	2.94	8.53	6.67	1.94	6.19	2.44	2.37	1.77	5.07
SUBJECT 4		G2L1P3	G2L1P1	G2L2P3	G1L1P1	G1L1P4	G1L3P3	G1L2P3	G1L3P1	G2L2P4	G1L2P1	G1L2P4	G1L1P3
	C2	1.71	1.33	1.98	2.24	0.83		2.27	1.85	0.57	1.95	1.74	1.22
		1.75	1.10	3.04	2.62	1.72	0.56	1.25	1.30	1.75	2.40	1.81	2.64
		3.28	4.25	7.93	5.29	6.42	4.57	4.62	4.97	1.77	3.97	3.02	2.76
		G1L2P2	G2L3P1	G1L2P4	G2L2P4	G1L1P3	G2L3P2	G1L3P1	G1L1P2	G1L2P1	G1L1P1	G2L2P1	G1L1P4
	C1	1.12	1.54	1.86	1.50	1.87	1.22	1.27	0.82	1.28	1.11	1.24	0.87
		1.29	0.87	1.50	1.13	1.91	0.82	1.30	1.46	1.33	1.02	0.81	1.24
		1.93	3.07	1.85	1.36	1.92	1.78	2.59	2.62	1.71	1.89	2.36	3.26
SUBJECT 5		G1L2P2	G2L1P3	G2L2P3	G1L1P3	G2L2P4	G1L3P4	G1L1P4	G1L2P2	G1L1P2	G1L1P3	G2L1P2	G2L1P4
	C2	0.92	2.78	2.64	2.60	2.59	2.79	1.92	1.43	1.34	2.80	1.41	1.77
		3.10	1.70	0.87	1.26	0.91	0.67	1.66	1.16	1.43	1.12	1.84	1.69
		1.78	5.96	2.21	1.15	2.69	2.23	4.08	4.14	2.02	6.67	2.04	4.74
		G1L1P4	G2L2P4	G2L1P1	G2L3P1	G2L3P4	G1L2P1	G1L1P3	G2L1P3	G1L3P1	G2L1P4	G1L3P3	G2L1P2
	C1	1.68	1.65	1.37	1.25	1.16	1.34	1.97	1.39	1.14	1.50	1.73	1.04
		1.75	0.97	0.91	0.44	1.59	0.59	0.83	1.24	0.70	1.12	0.81	0.80
		2.87	1.55	2.28	2.47	2.00	2.63	2.37	1.82	3.01	1.55	2.70	3.04
SUBJECT 6		G2L3P3	G2L2P4	G2L2P3	G2L1P4	G1L2P2	G1L3P1	G2L3P2	G2L1P3	G1L2P1	G1L1P1	G1L1P2	G2L1P2
	C1	1.00	2.31	1.43	2.24	2.26	1.13	1.47	1.02	1.24	1.40	1.56	1.10
		1.47	0.99	2.14	1.16	0.92	0.75	1.01	2.32	2.18	1.75	1.49	1.22
		2.60	2.80	3.21	2.47	6.37	7.89	1.64	2.90	5.40	4.11	5.58	3.02
		G1L2P2	G1L1P3	G1L1P4	G1L2P3	G1L3P3	G1L3P1	G2L1P1	G2L2P2	G2L3P2	G2L1P2	G2L2P3	G2L1P3
	C2	1.19	0.87	1.90	0.63	0.78	0.90	1.32	0.70	1.33	1.15	0.64	0.76
		0.83	2.62	3.33	1.93	2.07	1.95	1.49	0.60	0.45	1.09	3.10	2.53
		8.28	8.27	3.74	4.53	3.43	8.38	3.42	2.10	8.87	3.07	8.95	6.92

		13	14	15	16	17	18	19	20	21	22	23	24
SUBJECT 1		G2L3P2	G2L1P1	G1L3P3	G1L1P4	G1L2P2	G2L1P4	G1L2P3	G2L2P4	G2L3P4	G2L1P3	G2L2P1	G1L3P1
	C1	3.44	1.71	1.71	0.40	1.58	1.12	1.56	1.11	1.92	2.18	0.72	1.87
		1.18	1.57	0.52	1.81	1.08	1.52	0.74	1.54	0.87	1.24	0.68	1.70
		5.19	4.51	4.52	3.58	3.16	1.71	4.99	1.83	1.57	2.10	1.78	4.11
		G2L2P3	G2L1P3	G2L3P3	G1L3P1	G2L1P4	G2L3P2	G1L1P1	G1L2P1	G2L1P2	G1L1P4	G2L2P1	G2L1P1
	C2	2.13	2.32	1.88	2.97	1.75	1.68	2.37	2.62	1.61	1.82	1.76	1.83
		1.06	1.83	0.95	0.72	1.09	0.94	2.19	1.39	1.12	2.02	0.81	0.73
		3.86	3.25	2.50	2.95	5.57	1.86	4.55	3.78	4.02	3.78	7.22	2.96
SUBJECT 2		G1L3P1	G2L1P2	G2L1P4	G2L2P4	G1L2P2	G2L3P3	G2L2P3	G2L3P1	G1L3P3	G1L1P4	G2L3P4	G2L1P3
	C2	1.24	0.79	0.94	0.94	0.86	1.06	2.10	0.68	0.95	1.22	0.70	1.10
		0.70	0.96	1.20	1.07	0.71	0.87	2.71	0.98	0.92	4.05	1.07	2.40
		4.14	19.65	4.92	1.01	5.51	2.52	3.83	1.29	4.58	3.81	2.54	3.46
	C1	G2L3P2	G1L2P2	G1L1P3	G2L2P3	G1L2P3	G1L3P2	G2L3P3	G2L2P2	G1L2P4	G1L2P1	G2L1P4	G2L1P1
		0.78	0.89	0.83	0.78	0.84	0.59	0.85	0.78	0.64	0.61	0.59	0.63
		0.58	0.65	1.08	0.68	0.93	0.96	0.49	0.31	0.83	1.30	0.75	0.83
		2.26	2.41	2.60	0.65	3.38	1.94	0.59	1.99	2.09	3.97	2.84	2.97
SUBJECT 3		G1L2P1	G2L1P2	G1L3P1	G1L1P2	G1L2P4	G1L1P3	G2L2P4	G1L3P3	G1L2P3	G2L3P2	G1L2P2	G2L3P4
	C1	0.97	0.53	1.01	0.77	0.88	0.85	0.75	0.72	0.76	0.54	0.57	0.53
		1.18	1.60	1.50	1.70	1.33	1.24	0.93	1.18	1.25	0.85	1.33	1.00
		4.20	2.15	1.91	4.59	3.04	2.37	1.70	3.13	1.44	1.76	1.33	1.11
		G2L1P2	G1L1P3	G1L3P4	G2L2P1	G1L3P1	G2L3P3	G1L1P1	G2L2P3	G1L3P2	G2L1P4	G2L3P4	G2L3P1
	C2	0.60	1.12	0.99	0.78	1.24	0.89	0.81	0.98	0.66	0.98	0.96	0.93
		1.29	1.24	0.88	1.02	1.37	1.24	2.55	1.18	0.63	1.62	0.64	0.71
		1.23	2.71	3.97	1.99	2.30	1.82	3.40	1.68	3.31	2.07	1.46	1.37
SUBJECT 4		G1L1P2	G2L1P4	G1L3P4	G2L3P1	G2L1P2	G2L3P2	G1L3P2	G2L3P3	G1L2P2	G2L2P2	G2L2P1	G2L3P4
	C2	1.58	1.11	0.61	1.10	1.37	1.01	1.99	1.66	1.09	1.26		0.91
		1.34	2.35	1.73	1.79	1.23	0.82	1.11	1.84	1.62	1.23	2.19	1.07
		4.42	2.82	3.42	1.92	2.42	2.07	1.42	2.54	4.62	2.25	3.81	2.45
		G2L3P3	G2L1P2	G1L3P2	G1L3P4	G2L1P3	G2L1P1	G1L2P3	G2L2P2	G1L3P3	G2L1P4	G2L3P4	G2L2P3
	C1	1.55	1.21	1.56	1.65	1.46	1.20	1.91	1.23	1.82	1.23	0.81	1.56
		0.88	0.82	0.80	0.99	1.59	1.01	1.21	0.85	1.60	1.12	1.14	1.11
		1.40	2.40	3.01	2.53	1.51	2.57	2.84	1.67	1.51	1.26	1.33	1.50
SUBJECT 5		G1L3P3	G2L3P1	G2L3P3	G2L2P1	G2L1P1	G1L1P1	G1L3P1	G1L2P4	G1L3P2	G2L2P2	G2L3P2	G2L3P4
	C2	3.19	2.14	1.74	1.55	1.45	1.48	1.30	1.92	1.32	1.11	1.38	2.67
		2.00	0.81	0.53	0.82	1.44	2.42	0.91	0.91	0.66	1.05	0.78	2.30
		5.80	1.44	1.72	2.92	2.17	1.00	3.75	15.67	2.14	2.28	2.00	9.78
		G2L2P2	G1L1P1	G1L2P4	G1L3P2	G2L2P1	G1L2P3	G2L3P2	G1L1P2	G1L2P2	G1L3P4	G2L2P3	G2L3P3
	C1	1.14	1.14	1.35	1.20	1.22	1.47	0.89	1.28	1.96	1.40	1.33	0.95
		0.87	1.34	1.10	0.57	0.44	0.84	0.68	1.04	0.45	0.95	0.75	0.46
		2.16	2.53	2.97	2.45	3.13	2.18	2.28	2.83	1.95	2.14	2.74	1.84
SUBJECT 6		G1L2P4	G2L3P1	G1L2P3	G2L1P1	G1L3P4	G1L3P2	G2L2P2	G1L1P3	G2L3P4	G1L3P3	G2L2P1	G1L1P4
	C1	2.07	1.59	1.11	1.09	2.57	1.47	1.38	2.36	1.49	0.98	1.72	1.70
		1.54	1.06	2.15	1.49	0.89	0.97	1.50	3.71	0.79	1.29	2.62	1.32
		5.70	1.94	3.00	3.99	1.98	5.44	2.99	7.44	1.34	4.95	7.62	3.09
		G1L3P2	G2L2P1	G2L3P3	G2L1P4	G1L3P4	G2L3P4	G1L2P4	G1L1P1	G2L2P4	G1L1P2	G1L2P1	G2L3P1
	C2	1.19	1.13	0.85	1.53	2.09	1.92	1.63	2.37	0.77	1.17	1.22	0.98
		0.58	0.77	2.34	2.58	1.00	0.80	1.17	2.53	1.54	1.37	1.92	0.87
		9.09	4.36	7.00	9.85	3.27	8.05	8.03	4.62	2.50	4.78	8.38	1.72

*Clothing	Body Position-Handhold Combination
C1-Unsuited	P1-Headfirst - side, side
C2-Suited	P2-Headfirst - bottom, bottom
	P3-Feetfirst - side, side
Gravity	P4-Feetfirst - top, top
G1-Zero G	Iris Clearance
G2-Lunar G	
	L1-+1 inch
	L2-+5 inches
	L3-+10 inches

BEST AVAILABLE COPY

TABLE I (Concluded)

		1	2	3	4	5	6	7	8	9	10	11	12
SUBJECT 7		G2L1P3	G2L2P4	G1L2P2	G2L2P2	G2L3P4	G2L1P4	G1L2P3	G2L2P3	G2L3P1	G1L3P4	G1L1P2	G1L2P1
	C1	0.54	1.75	1.23	0.71	1.21	1.21	0.63	0.62	1.03	0.43	0.66	0.69
		2.57	1.17	1.88	1.11	1.03	1.18	2.25	1.57	1.01	1.50	1.14	1.67
		4.08	4.01	6.50	4.29	2.91	2.02	3.88	1.51	3.87	3.73	5.48	4.85
		G2L3P4	G2L2P4	G2L1P2	G1L2P2	G2L1P4	G1L3P3	G2L2P3	G1L1P2	G1L2P4	G2L3P2	G2L2P2	G2L2P1
	C2	3.85	1.48	0.70	5.05	1.70	1.01	0.89	5.99	1.42	0.52	0.60	1.04
		1.24	1.60	2.02	1.67	1.11	4.07	4.95	1.88	1.04	1.04	1.20	1.09
		3.13	3.12	3.89	5.03	3.43	8.68	3.14	6.81	7.66	3.33	3.31	3.68
SUBJECT 8		G2L3P1	G2L1P1	G2L1P4	G1L2P2	G2L1P2	G1L3P1	G1L1P2	G1L3P2	G2L3P3	G2L3P2	G1L3P4	G1L1P4
	C1	2.44	2.29	2.70	2.03	1.72	2.75	2.14	2.08	2.34	1.34	2.38	2.35
		0.99	1.32	1.64	1.42	1.28	1.11	2.75	1.55	0.95	0.86	1.93	2.37
		4.99	5.86	3.45	3.97	3.16	4.95	3.53	2.51	2.85	3.39	3.38	5.31
		G2L3P2	G1L1P3	G1L2P2	G1L1P2	G1L2P4	G1L2P3	G2L2P4	G2L2P1	G1L3P1	G1L3P4	G1L2P1	G2L3P3
	C2		3.65	3.24	5.94	4.32	4.41	2.69	2.49	3.12	2.91	2.67	2.58
		1.42	5.49	2.63	2.18	2.19	3.51	4.10	2.82	2.30	2.37	4.28	1.84
		5.88	3.76	3.24	8.14	4.69	3.45		7.82	6.84	13.00	5.47	5.25
SUBJECT 9		G1L1P4	G2L1P2	G2L2P1	G2L2P4	G2L1P3	G1L2P1	G2L2P2	G2L1P1	G2L3P3	G1L2P4	G1L3P4	G2L3P4
	C2	2.62	1.30	1.93	2.37	2.19	1.93	1.35	1.41	2.42	2.20	1.94	1.35
		2.22	3.09	2.23	2.85	2.34	2.22	1.94	1.78	1.43	1.37	1.09	1.45
		4.23	2.03	3.80	5.51	2.47	6.83	3.60	4.98	5.44	5.77	4.34	1.98
		G1L1P3	G1L1P2	G1L3P2	G1L2P4	G2L2P1	G1L3P1	G2L1P3	G2L3P1	G2L1P4	G2L2P2	G1L1P2	G2L1P2
	C1	2.27	1.64	1.87	1.50	1.14	1.00	2.05	0.92	0.73	1.05	1.59	0.63
		2.27	2.60	1.94	2.43	2.53	1.49	1.37	2.14	1.67	2.19	3.53	1.75
		3.64	4.82	5.62	3.89	3.33	3.46	2.09	1.83	2.71	3.02	2.02	2.45
SUBJECT 10		G2L1P4	G1L3P1	G1L1P1	G1L1P3	G1L2P1	G2L1P1	G1L3P2	G1L3P4	G2L1P2	G1L2P3	G1L1P2	G2L2P1
	C2	1.79	0.89	2.02	1.76	1.50	0.71	0.54	1.02	0.67	1.11	0.45	0.76
		0.81	1.11	1.99	1.15	0.45	1.12	0.83	0.33	0.86	1.11	1.15	0.89
		5.80	8.06	6.97	5.99	6.87	5.96	3.95	5.60	3.56	2.97	4.24	4.66
		G1L3P3	G1L2P1	G2L2P4	G1L2P4	G1L3P4	G2L3P1	G2L2P1	G1L2P2	G2L1P2	G2L3P2	G1L1P3	G2L1P1
	C1	1.40	2.28	0.75	1.11	1.43	0.72	0.75	0.59	0.76	0.65	1.18	0.73
		2.09	1.95	1.05	1.12	0.90	0.48	1.39	1.10	2.71	0.55	1.07	1.20
		2.46	3.53	1.39	2.90	1.37	4.55	1.75	1.80	2.04	4.81	3.12	2.22
SUBJECT 1A		G2L2P2	G1L3P4	G1L3P2	G2L2P3	G1L2P1	G1L1P3	G2L1P2	G1L2P4	G1L1P2	G2L3P1	G1L1P1	G2L3P3
	C1	1.28	1.32	0.61	1.01	1.95	1.08	0.63	1.27	1.19	0.64	1.61	0.94
		1.03	0.87	1.00	0.86	0.86	1.59	0.84	0.80	2.05	0.63	1.57	0.59
		1.46	4.39	1.61	1.78	2.39	4.22	0.76	1.81	3.09	2.22	1.67	1.62
		G1L3P2	G2L3P4	G1L3P3	G1L1P3	G1L3P4	G2L3P1	G2L2P4	G1L2P2	G1L2P1	G2L2P2	G1L2P3	G1L1P2
	C2	2.18	1.29	1.82	1.28	1.37	1.12	0.98	0.60	1.65	0.64	1.71	0.59
		2.88	1.09	1.01	1.43	1.13	0.69	0.81	1.96	0.76	1.11	1.03	2.74
		4.94	1.89	5.72	6.29	1.71	1.87	3.00	3.60	9.48	2.52	3.10	4.51
SUBJECT 2A		G1L1P1	G1L3P2	G1L2P4	G1L3P4	G2L3P2	G1L2P3	G2L2P1	G1L1P3	G2L2P2	G1L1P2	G1L2P1	G2L1P1
	C2	0.90	0.80	1.00	0.91	0.63	1.30	0.69	1.22	0.86	0.86	1.66	0.79
		0.99	1.18	1.13	0.50	0.69	0.49	0.51	0.83	0.34	0.38	0.88	0.99
		2.17	5.23	3.42	1.00	0.39	8.80	1.03	3.13	3.14	2.41	4.65	2.64
		G2L1P3	G2L3P4	G1L3P3	G2L1P2	G1L3P1	G2L2P1	G1L1P2	G1L3P4	G1L1P1	G1L1P4	G2L3P1	G2L2P4
	C1	0.95	0.81	0.99	0.56	0.79	0.67	0.70	0.92	0.76	0.78	0.65	0.77
		0.96	0.47	0.58	1.01	0.54	0.46	1.05	0.75	1.38	0.75	0.85	0.78
		2.53	2.40	4.64	1.79	2.56	3.94	4.29	0.76	2.65	2.40	1.53	1.55
SUBJECT 5A		G1L2P1	G2L1P3	G2L2P3	G1L1P3	G2L2P4	G1L3P4	G1L1P4	G1L2P2	G1L1P2	G2L2P3	G2L1P2	G2L1P4
	C2	1.20	1.86	1.41	1.57	1.47	1.39	0.83	0.84	1.45	1.48	0.64	0.81
		0.92	1.26	0.86	1.07	0.87	0.78	1.55	0.88	1.34	0.67	0.96	1.39
		2.80	3.00	2.14	2.31	2.34	2.36	3.01	2.95	1.50	2.34	4.41	2.00
		G1L1P4	G2L2P4	G2L1P1	G2L3P1	G2L3P4	G1L2P1	G1L1P3	G2L1P3	G1L3P1	G2L1P4	G1L3P3	G2L1P2
	C1	0.85	0.98	0.95	0.78	0.73	0.92	1.07	1.15	0.99	0.89	1.10	0.86
		1.29	0.86	0.45	0.32	0.75	0.97	0.99	0.79	0.39	1.06	0.67	1.52
		1.14	0.85	1.30	4.27	1.57	1.64	4.95	2.78	1.82	2.11	2.09	1.78

		13	14	15	16	17	18	19	20	21	22	23	24
SUBJECT 7		G2L2P1	G2L3P2	G1L1P3	G2L1P2	G1L1P1	G2L1P1	G1L2P4	G1L3P2	G1L3P3	G1L3P1	G2L3P3	G1L1P4
	C1	0.71	0.52	0.46	1.03	0.47	0.85	0.34	0.51	0.36	0.70	0.57	0.44
		1.83	0.44	1.43	1.24	2.43	0.94	0.78	0.61	1.54	1.41	1.24	1.04
		3.97	3.37	2.64	3.03	3.61	2.92	4.17	5.62	0.80	3.98	2.23	4.56
		G1L1P4	G1L2P1	G2L3P1	G1L3P1	G2L3P3	G1L3P4	G1L1P3	G1L1P1	G1L3P2	G1L2P3	G2L1P3	G2L1P1
	C2	1.07	2.33	0.88	0.74	1.97	1.22	1.43	1.00	0.58	1.47	1.27	0.66
		1.35	1.00	1.05	1.02	1.64	1.20	2.80	5.54	0.80	1.79	5.40	3.34
		6.98	6.19	6.37	9.13	3.40	6.04	4.29	0.98	5.39	2.51	6.71	6.16
SUBJECT 8		G1L1P3	G1L2P4	G1L3P3	G2L2P4	G1L2P3	G1L2P1	G2L2P3	G1L1P1	G2L1P3	G2L2P1	G2L3P4	G2L2P2
	C1	2.45	4.19	2.73	2.37	2.15	1.98	1.64	1.80	2.04	1.55	2.09	1.21
		1.60	0.80	0.75	0.81	1.47	3.07	0.88	1.54	1.00	0.93	0.99	1.22
		2.26	3.77	3.01	2.53	3.38	4.29	2.37	2.71	2.34	3.10	2.24	1.98
		G2L1P1	G2L1P3	G1L1P4	G2L3P4	G1L1P1	G2L3P1	G1L3P2	G2L2P3	G2L1P2	G2L1P4	G2L2P2	G1L3P3
	C2	1.72	2.23	2.96	1.53	3.10	1.88	1.82	1.95	1.64	1.91	1.79	2.87
		2.63	2.37	6.62	1.80	4.67	3.94	1.96	1.24	3.27	5.41	2.17	1.72
		3.52	4.52	1.60	6.52	4.65	3.20	6.77	4.60	4.60	5.14	4.57	4.00
SUBJECT 9		G1L1P3	G1L1P1	G2L1P4	G1L3P1	G1L2P3	G1L3P3	G1L1P2	G2L2P2	G1L3P2	G2L2P3	G2L3P1	G1L2P2
	C2	2.11	1.99	1.76	1.91	1.53	1.90	2.13	1.40	1.47	2.02	1.84	1.76
		2.71	3.95	1.38	1.77	0.98	1.39	3.11	3.05	1.43	2.34	1.48	2.70
		4.54	4.80	3.31	3.26	3.37	2.76	4.21	3.00	1.52	1.88	2.05	5.87
		G2L3P4	G1L1P4	G1L3P4	G1L2P3	G1L2P1	G2L1P1	G1L1P1	G2L3P3	G2L2P4	G2L3P2	G1L3P3	G2L2P3
	C1	1.73	1.68	1.47	1.61	1.36	1.03	1.17	1.78	1.27	0.83	1.82	1.37
		0.78	1.88	1.32	1.54	2.88	1.74	1.61	0.96	1.09	1.25	0.96	1.31
		1.47	3.26	4.98	1.07	1.74	2.45	3.16	2.34	1.41	3.50	4.00	1.87
SUBJECT 10		G2L2P4	G2L3P3	G1L2P2	G1L3P3	G1L1P4	G2L2P2	G2L3P4	G2L3P1	G2L2P3	G1L2P4	G2L1P3	G2L3P2
	C2	0.61	1.45	0.80	1.82	1.21	0.60	1.42	1.49	1.43	1.44	1.14	0.75
		0.81	0.46	1.27	0.81	1.62	0.80	0.54	0.98	1.27	1.06	1.45	0.62
		2.43	4.08	7.16	7.41	2.88	5.05	2.32	1.60	5.02	5.08	1.89	4.04
		G1L1P1	G2L2P2	G2L3P3	G2L1P4	G1L2P3	G1L1P4	G2L1P3	G1L1P2	G1L3P1	G2L2P3	G2L3P4	G1L3P2
	C1	0.76	0.72	0.98	0.63	1.06	0.73	0.99	0.92	0.79	1.03	0.77	0.75
		1.11	1.13	0.69	1.79	1.16	1.43	1.10	0.85	1.20	0.75	0.78	0.52
		4.20	4.06	1.45	1.53	1.46	1.86	1.29	4.25	2.00	1.22	0.99	3.35
SUBJECT 1A		G2L3P2	G2L1P1	G1L3P3	G1L1P4	G1L2P2	G2L1P4	G1L2P3	G2L2P4	G2L3P4	G2L1P3	G2L2P1	G1L3P1
	C1	0.68	1.09	1.29	1.44	1.26	0.72	1.48	0.72	1.03	0.65	1.09	1.22
		0.99	1.25	0.87	0.79	0.71	1.26	0.88	0.85	0.73	1.03	1.91	2.76
		2.88	2.16	2.67	2.26	4.24	1.95	3.11	2.43	1.59	2.16	2.04	1.63
		G2L2P3	G2L1P3	G2L3P3	G1L3P1	G2L1P4	G2L3P2	G1L1P1	G1L2P1	G2L1P2	G1L1P4	G2L2P1	G2L1P1
	C2	0.95	1.05	1.06	0.97	1.24	0.63	1.47	1.31	0.59	1.08	0.71	0.83
		1.19	1.53	0.63	1.51	2.35	0.91	2.00	2.01	1.76	1.26	0.70	1.88
		2.47	1.68	1.67	4.46	2.14	1.93	3.24	8.20	3.53	5.47	3.00	2.34
SUBJECT 2A		G1L3P1	G2L1P2	G2L1P4	G2L2P4	G1L2P2	G2L3P3	G2L2P3	G2L3P1	G1L3P3	G1L1P4	G2L3P4	G2L1P3
	C2	0.77	0.73	0.93	0.77	1.00	0.76	0.82	0.74	0.88	0.84	0.77	0.89
		0.75	0.56	1.29	0.73	0.60	0.74	1.01	0.97	0.84	2.57	0.68	2.38
		7.86	2.41	2.60	1.82	8.51	0.76	2.00	1.60	5.43	5.50	1.82	3.53
		G2L3P2	G1L2P2	G1L1P3	G2L2P3	G1L2P3	G1L3P2	G2L3P3	G2L2P2	G1L2P4	G1L2P1	G2L1P4	G2L1P1
	C1	0.70	0.78	1.05	0.70	0.69	0.93	0.93	0.81	1.10	0.93	0.71	0.89
		0.58	0.49	0.73	0.91	0.61	0.51	0.53	0.67	0.73	0.77	0.72	0.59
		1.72	4.15	1.95	0.92	3.98	2.48	1.34	1.33	0.83	2.21	1.42	2.44
SUBJECT 5A		G1L3P3	G2L3P1	G2L3P3	G2L2P1	G2L1P1	G1L1P1	G1L3P1	G1L2P4	G1L3P2	G2L2P2	G2L3P2	G2L3P4
	C2	1.05	0.97	1.09	0.96	0.92	1.10	1.13	0.86	1.37	0.99	1.02	1.44
		0.79	0.69	0.52	0.67	1.15	1.24	0.86	1.60	1.03	0.90	0.43	0.69
		1.86	1.55	1.72	1.59	1.99	1.22	2.50	1.24	0.88	4.00	1.06	0.97
		G2L2P2	G1L1P1	G1L2P4	G1L3P2	G2L2P1	G1L2P3	G2L3P2	G1L1P2	G1L2P2	G1L3P4	G2L2P3	G2L3P3
	C1	0.61	0.91	1.01	0.65	0.75	1.21	0.61	0.64	0.77	0.69	0.69	0.73
		0.90	1.16	1.09	0.71	0.99	0.54	0.34	0.92	0.88	0.76	0.67	0.75
		1.35	1.62	1.68	3.32	1.01	1.91	2.26	2.09	1.75	2.87	1.78	1.48

The body plane information was used to compare pressure-suited and unsuited subjects.

SECTION III

RESULTS

TIME AND CONTACT SCORES

Means for the various clothing, gravity, iris clearance, and position-handhold conditions are plotted in the following figures. The body of this report treats data from the "replication group" of subjects.

Total Time

Total time is the time required for the entire motion sequence of launching, egress and landing.

Pressure suited motions required 32% more time than unsuited motions. Motions performed during zero G required 35% more time than equivalent motions performed during lunar G. (See figure 5.)

The headfirst-bottom handhold technique for iris passage was the quickest method, and the feetfirst-side technique was the slowest method. The latter required 15% more time than the former. It appeared to be easier to tuck the arms under the body rather than to the side of the torso. The latter technique frequently caused underarm hangups.

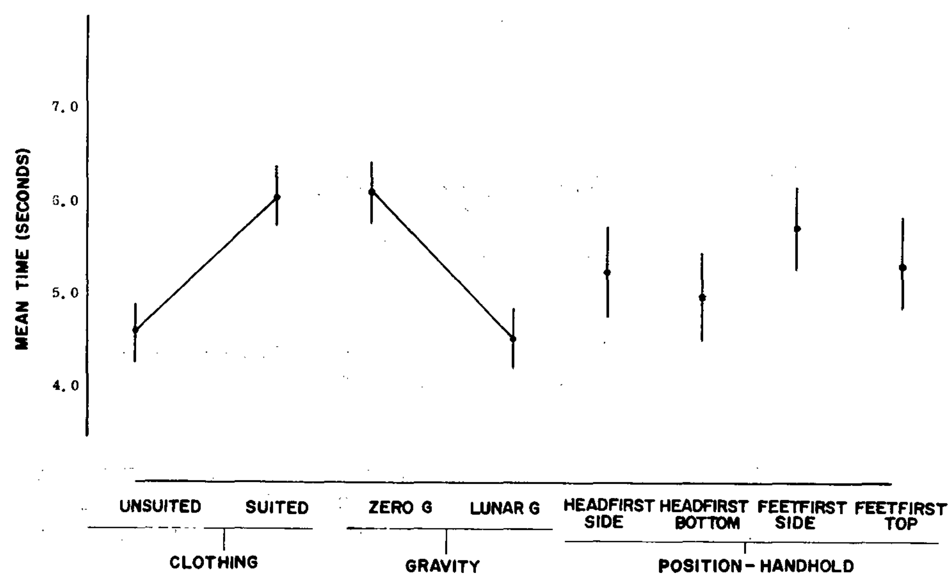


Figure 5. Total Time - Two Clothing Conditions, Two Gravity Conditions, Four Body-Handhold Positions. Dot represents mean and vertical bar indicates where the mean will fall 95 per cent of the time.

Figure 6 indicates that approximately 30% more time was required under zero G than under lunar G when unsuited and 40% more time when suited. In approximate terms, a suited subject performed as well at lunar G as an unsuited subject at zero G. Apparently the mobility restrictions of the suit were matched by the poorer body control during the zero-G condition.

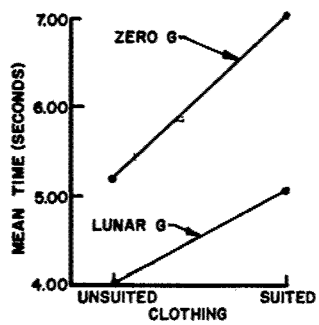


Figure 6
Total Time - Two Clothing Conditions for Two Gravity Conditions

Dot represents mean.

Figure 7 shows that for all body-handhold position combinations, the suited condition was inferior to the unsuited condition under all gravity conditions.

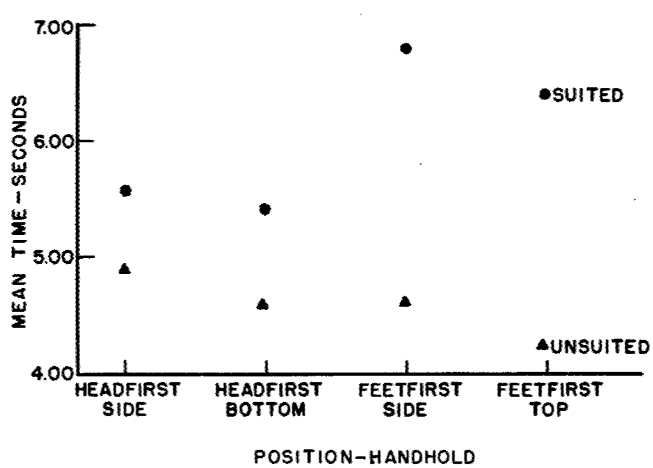


Figure 7. Total Time - Time Plot of Four Body-Handhold Positions for Two Clothing Conditions

Figure 8 suggests that under the lunar-G condition the four egress techniques are virtually equivalent. However, under the zero-G conditions, the side handhold appears to be definitely inferior to other techniques. The difficulty of this egress technique appears to be in lunging and landing. The problem is exaggerated in the suited condition (see figures 4 and 11). It was difficult for a suited subject to raise his arm sideways, over his head.

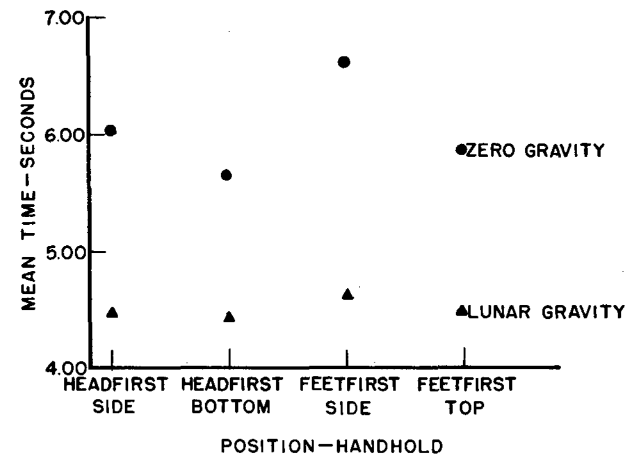


Figure 8. Total Time - Four Body-Handhold Positions for Two Gravity Conditions

Lunge Time

The approach to the iris consisted of a set of smooth motions. Rather than standing up, walking, leaning, and jumping, most subjects used a single, seat-launched lunge motion. Under both lunar- and zero-G conditions, their feet normally left the floor before their hands left the armrest (the right-hand release started the first timer). This takeoff posture was particularly evident when they used a feetfirst egress technique. In this case, a hand-launched thrust rather than a foot-launched thrust was clearly evident. Frequently, for foot-first approaches, subjects did not change from their sitting posture until well through the iris.

Figure 9 shows that the lunge motion under suited conditions required 32% more time than under unsuited conditions, and the motion during zero G required 17% more time than during lunar G. The cause of the latter appeared to be the subject's poorer body control after they grasped the handholds.

The headfirst-bottom technique was the quickest and feetfirst-side technique the slowest, with the latter requiring 42% more time than the former. The latter required a body rotation while using side handholds (biomechanically, an awkward motion). The former technique often required handholds only to guide the momentum attained during the initial seat-launched lunge. Several subjects sailed headfirst through the larger clearances without touching the bottom or side handholds.

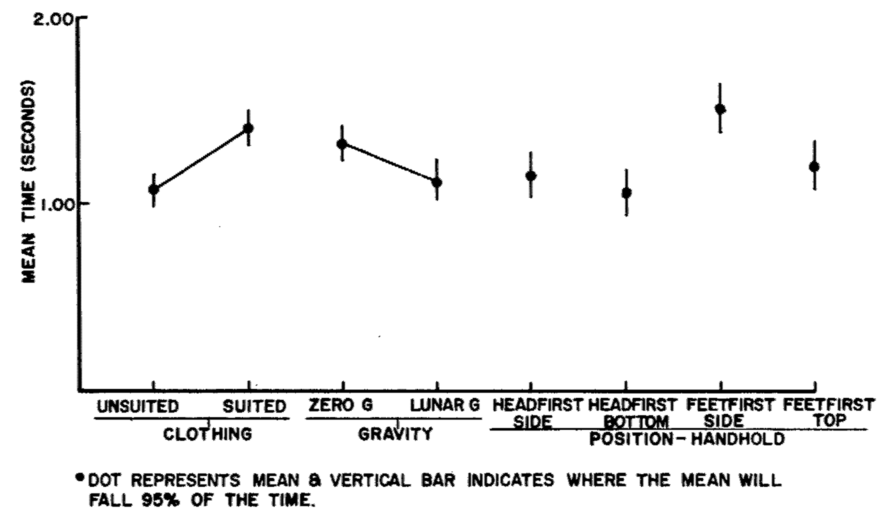


Figure 9. Lunge Time - Two Clothing Conditions, Two Gravity Conditions, Four Body-Handhold Positions

Figure 10 indicates that lunging at zero G required from 11% (unsuited) to 22% (suited) more time than did lunging under lunar-G conditions.

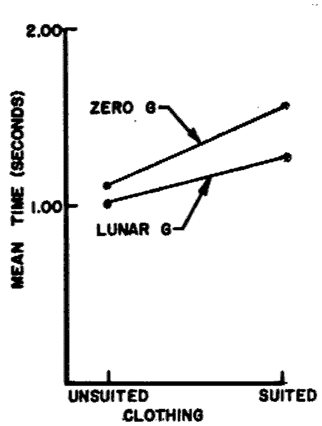


Figure 10
Lunge Time - Two Clothing Conditions for Two Gravity Conditions

Dot represents mean

Figures 11 and 12 again reveal the awkwardness of the feetfirst-side handhold technique, especially under zero-G and suited conditions. The feetfirst-side technique required 21% more time under zero-gravity conditions and 64% more time under suited conditions than the quickest technique (figure 12). The pressure suit appeared to amplify a difficulty that also existed for the unsuited subject.

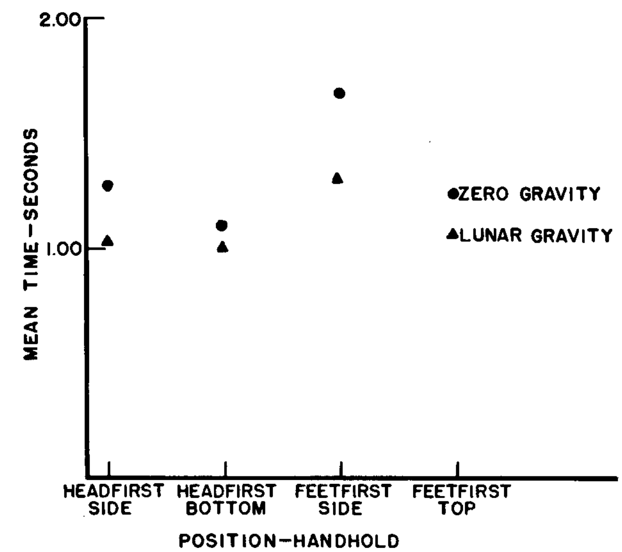


Figure 11

Lunge Time - Four Body-Handhold Positions for Two Gravity Conditions

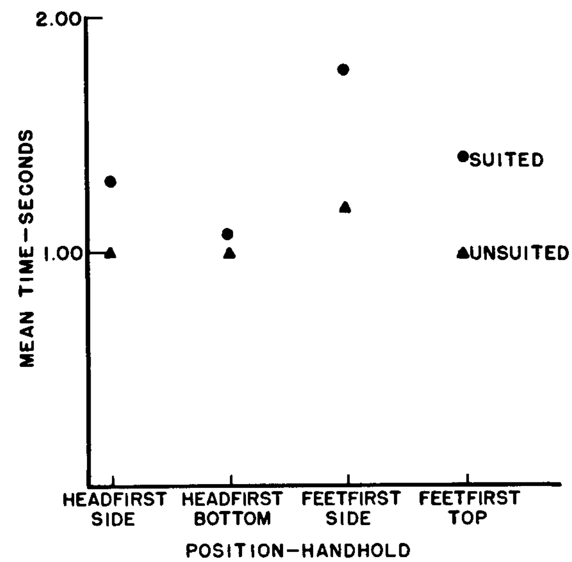


Figure 12

Lunge Time - Four Body-Handhold Positions for Two Clothing Conditions

Egress Time And Contacts

Figure 13 indicates that suited subjects required 34% more time to egress than unsuited subjects. Nineteen percent more time is required under zero G than under lunar G. Since egress times were less for lunar G than for zero G (and one could assume that egress time would be considerable longer at earth gravity), there is probably a G-level between zero G and one G for which egress time will be minimum. This suggests that there is an optimum G-level for other motions. If so it would provide another criteria for selecting an artificial G-level for rotating space stations.

Egress time was inversely related to iris clearance. Iris clearance of 1-inch required 55% more time for egress than 10-inch clearance, and a 5-inch clearance required 11% more time than a 10-inch clearance. The curve appears to approach an asymptote between 5 and 10 inches of clearance. The only aborted trials (a subject stuck in the iris, unable to move) occurred with a 1-inch iris clearance.

Particularly significant was the finding that most of the position-handhold techniques were similar in terms of time but dissimilar in terms of contacts.

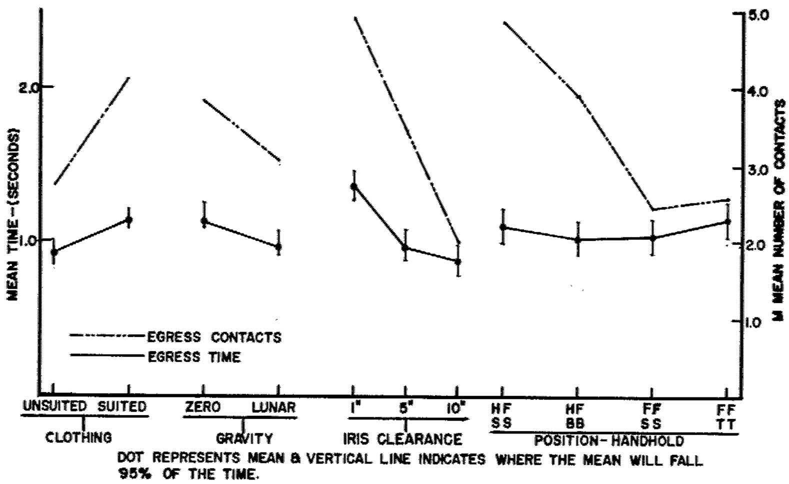
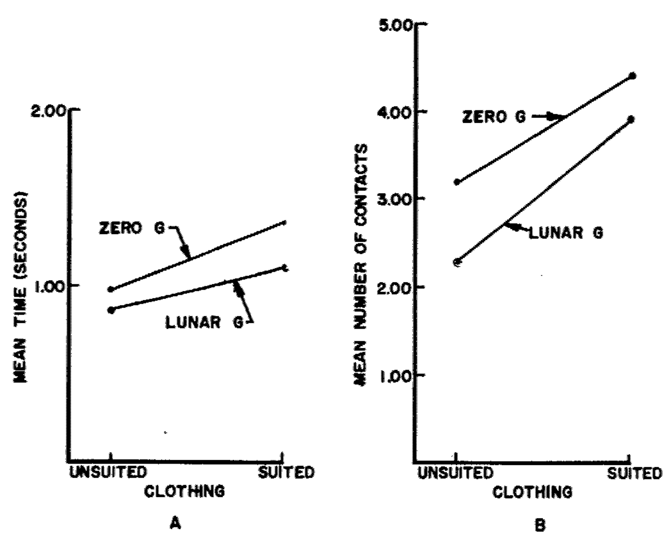


Figure 13. Egress Task-Time and Contacts: Two Clothing, Two Gravity, and Three Iris Clearance Conditions; Four Body-Handhold Positions

Figure 14 indicates that egress times and number of contacts are greatest for the suited, zero-G condition.



Dot represents mean

Figure 14. Egress Task - Time (A) and Contacts (B); Two Clothing Conditions for Two Gravity Conditions

Figures 15 and 16 suggest that the greatest time improvement occurs

in the 1- to 5-inch clearance range, wheras contacts decrease linearly over the entire 1- to 10-inch clearance range.

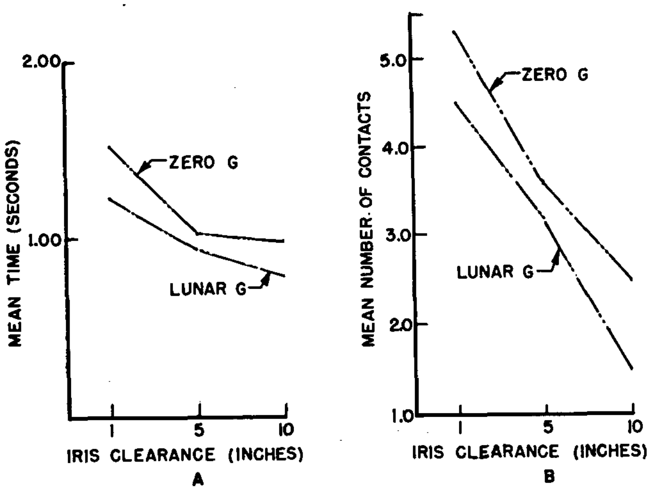


Figure 15

Egress Task - Time (A) and Contacts (B); Three Iris Clearances for Two Gravity Conditions

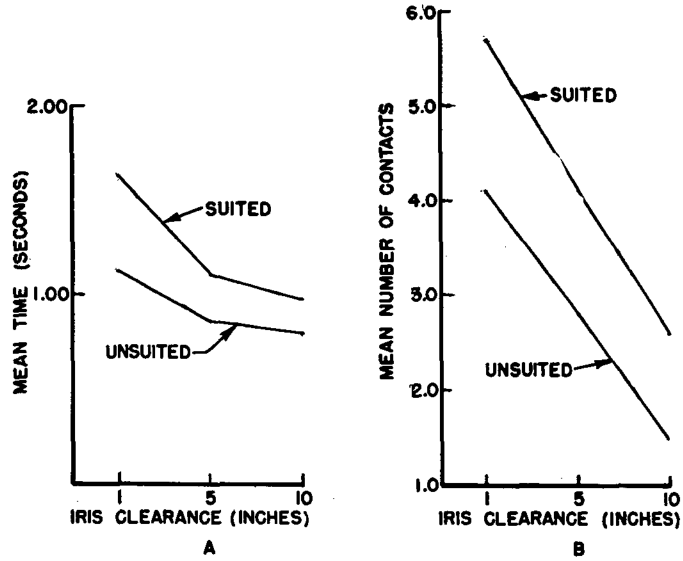


Figure 16

Egress Task - Time (A) and Contacts (B); Three Iris Clearances for Two Clothing Conditions

Figures 17 and 18 indicate that the feetfirst techniques, although the slowest for lunging and landing, yielded the smoothest egress, probably due to the subjects' ability to see their legs in relationship to the iris and thus better position their lower torso. (Several suited subjects reported that they did not know where their legs were, apparently due to poor kinesthetic feedback because of the lack of forces on the pressure receptors while suited under pressure and sailing over, rather than walking on, the floor. Accuracy of motion rather than time of motion may be a more sensitive measure of operator performance for the egress motion; however, the absolute number of contacts is too small to confirm this hypothesis.)

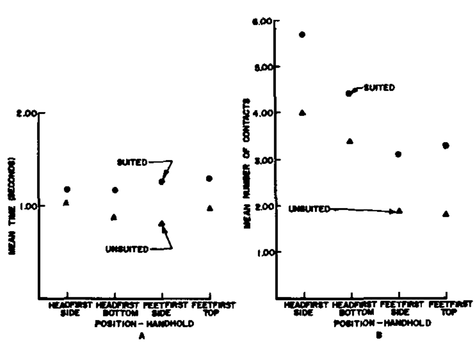


Figure 17. Egress Task - Time (A) and Contacts (B); Four Position-Handhold Conditions for Two Clothing Conditions

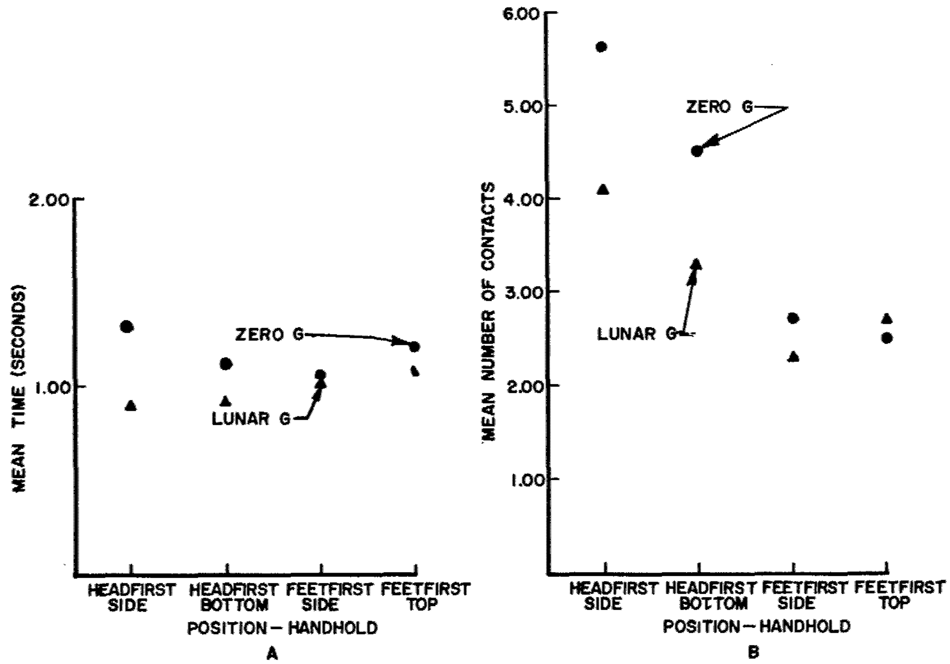


Figure 18. Egress Task - Time (A) and Contacts (B); Four Body-Handhold Positions for Two Gravity Conditions

Figure 19 (A) indicates that increasing the clearance from 1 to 5 inches reduces egress time appreciably whereas further increase from 5 to 10 inches does not. Again, contact scores appear to decrease fairly systematically over the 10-inch range and again suggest that the feetfirst techniques may be slightly better. One could speculate that if the subjects had taken more time, the contact scores would probably decrease but the relative differences between techniques would probably be maintained.

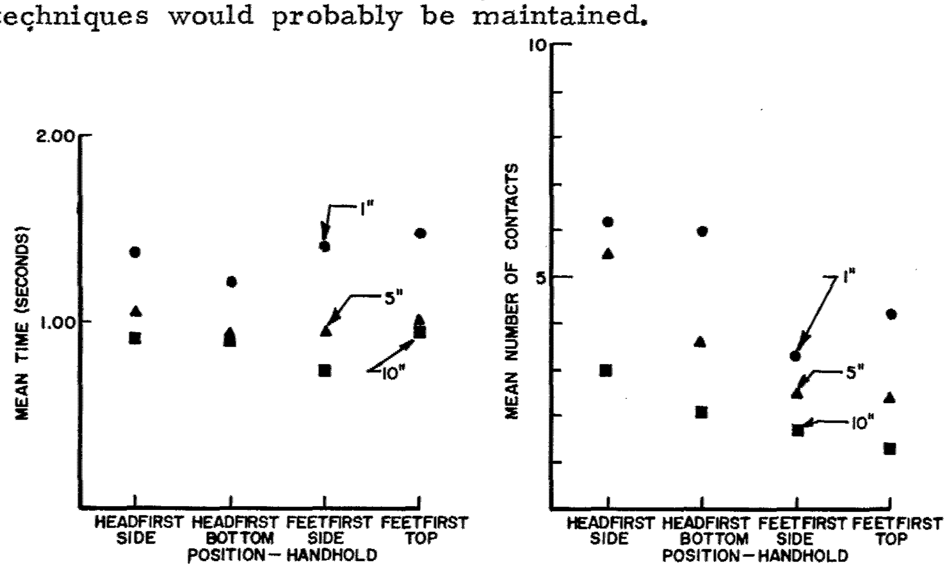


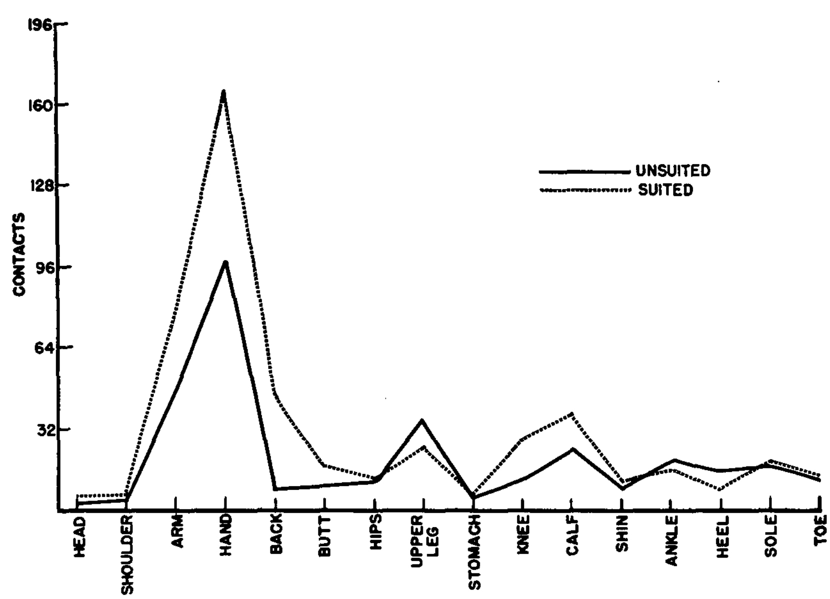
Figure 19. Egress Task - Time (A) and Contacts (B); Four Body-Handhold Positions for Three Iris Clearances

Egress Contacts By Body Segment

Figures 20(A) and 20 (B) suggests that the number of upper torso contacts was consistently higher for the suited and zero-G conditions, whereas the lower torso contacts appear to be random. One could suppose that the upper torso contacts were purposive and that lower torso contacts were generally aimless and the result of flailing limbs. Figure 20 (C) indicates a progressive decrease in the number of contacts for the upper torso as iris clearance increases; however, lower torso contacts again appear to be random throughout the iris clearance range.

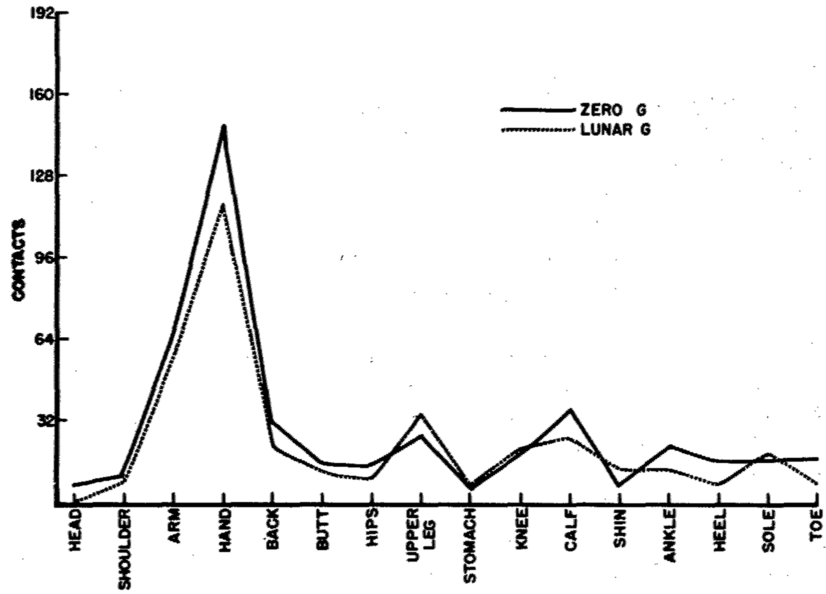
Future studies should attempt to isolate purposeful from inadvertent contacts, so that a contact measure truly reflects either accurate or inaccurate flight paths but not both categories. For example, the soles-of-the-feet contacts for feetfirst approaches (figure 20 (E)) could probably be considered as deliberate contacts.

The authors expected rather large differences between gravity levels when the subjects' feet left the floor for the egress task. It was supposed that the subjects would tend to scrape through the iris during lunar G because of the small but definite downward attraction of gravity. Figure 20 (B), however, indicates that the lunar-G condition yields fewer contacts than the zero-G condition. The difference is probably due to the more accurate body control of the subject during the lunar-G approach task.

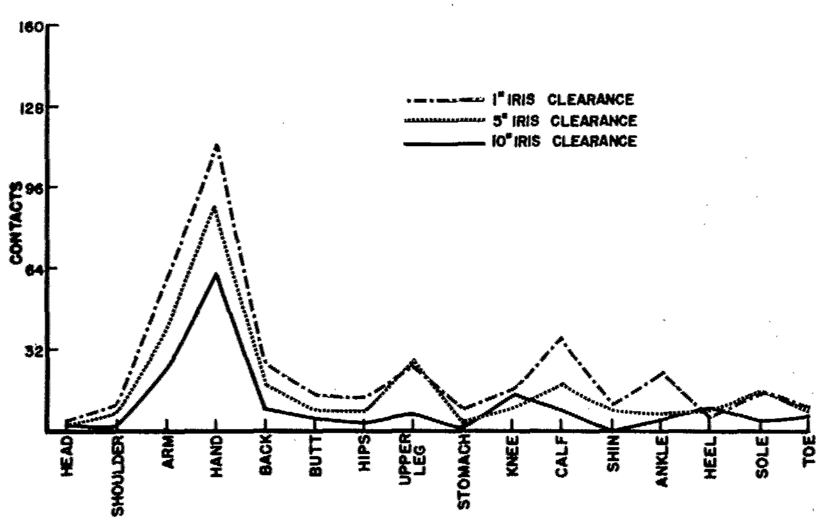


(A)

Figure 20. Total Number of Contacts for Each Body Segment



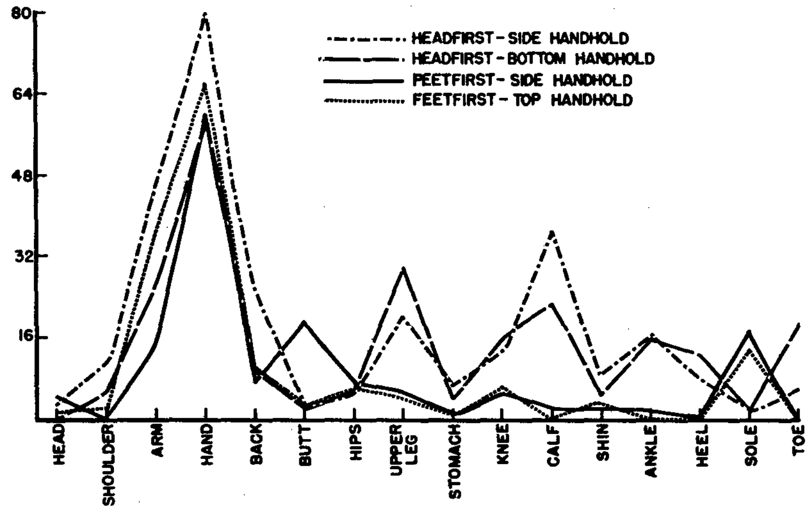
(B)

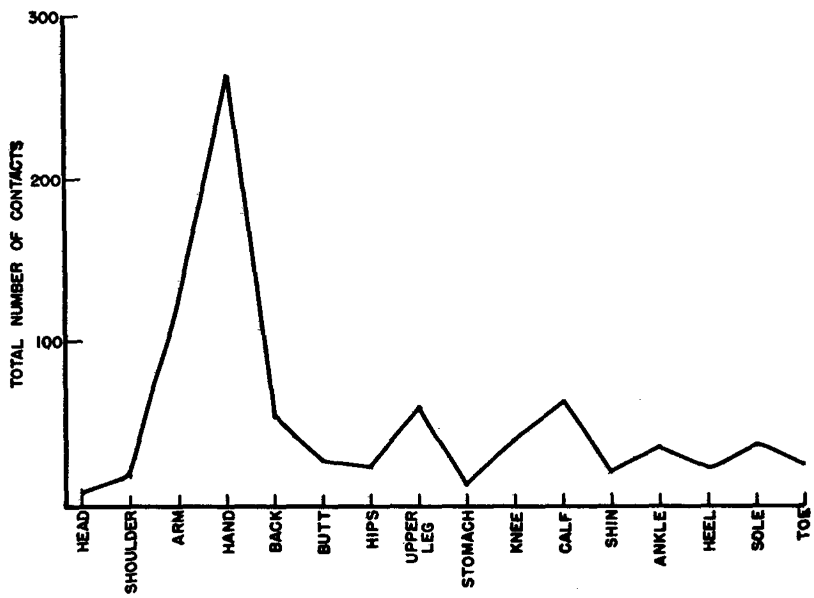


C (left)

Figure 20. (Continued)

D (right)





E (left)

Figure 20. (Concluded)

Landing Time

Figure 21 indicates that suited landing motions required 31% more time than unsuited motions. Motions during zero G required 50% more time than during lunar G. This extremely large time difference suggests the relative

helplessness of the flailing subject attempting to reach a surface during the zero-G condition.

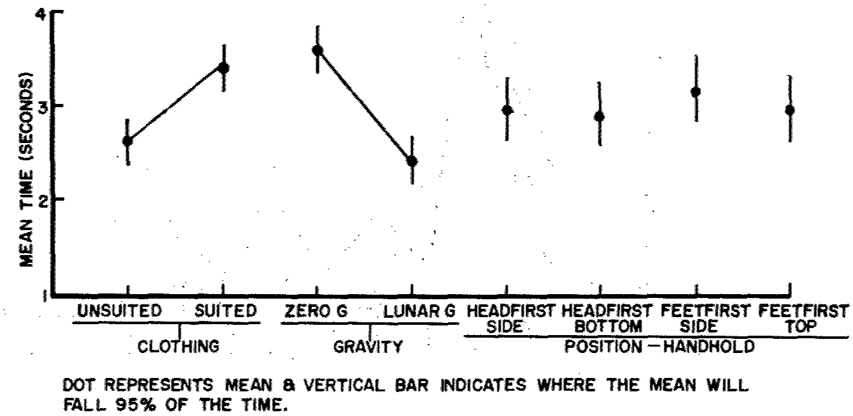
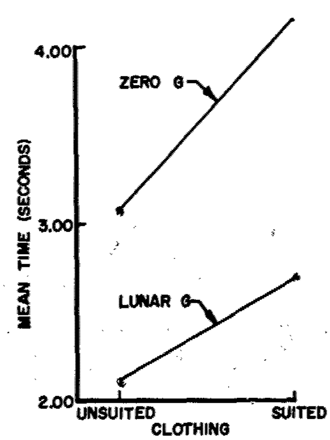


Figure 21. Landing Time - Two Clothing Conditions, Two Conditions, Four Body-Handhold Positions

Figure 22 indicates that suited subjects require 54% more time, and unsuited subjects require 45% more time, to land under zero-G conditions than under lunar-G conditions.



Dot represents mean

Figure 22. Landing Time - Two Clothing Conditions for Two Gravity Conditions

Figure 23 suggests that arriving hands-first enhances body control under suited conditions. Frequently subjects overshot or missed the seat

and found it difficult to turn around and align with the seat when arriving feet-first. Subjects often found themselves hovering over the seat during zero G and awkward pushing motions were made on cabin surfaces when the subjects could not grasp the seat. Such difficulties are reflected in the time scores presented in figure 24. With small iris openings, it was difficult to see around ones legs to the landing area.

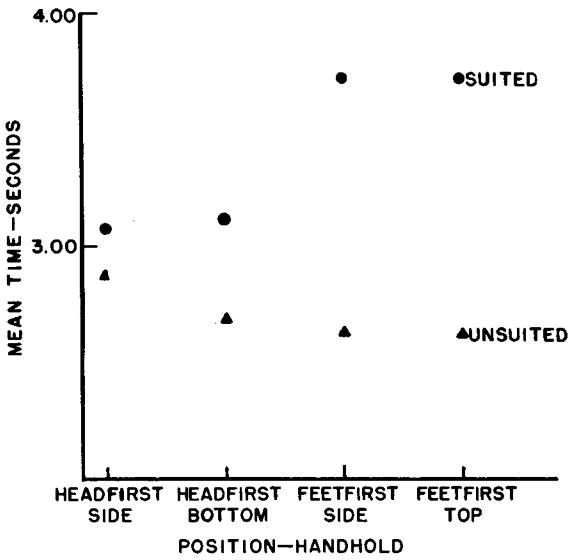


Figure 23

Landing Time - Four Body-Handhold Positions for Two Clothing Conditions

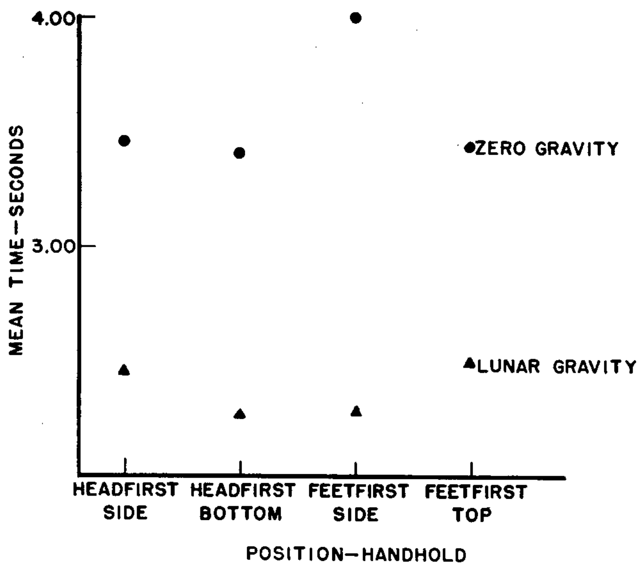


Figure 24

Landing Time - Four Body-Handhold Positions for Two Gravity Conditions

An analysis of film from Camera No. 1 revealed that both the face and anterior chest planes passed through approximately the same planes as well as the same number of planes in both the unsuited and suited conditions. This suggests that although the use of a pressure suit may retard joint range motion, it does not significantly alter total gross body movement or head rotation during the accomplishment of a gross body task.

HANDHOLD PREFERENCES

An analysis of film from Camera No. 3 (subjects ingressing through the iris) revealed hand-position preferences for each of the three fixed handholds (top, sides and bottom). When the top bar was used for ingress, all subjects gripped the bar in a palm-down attitude (pronated). When the side handholds were used, 90% of all trials were accomplished with the palms facing medially. For the bottom handhold, 90% of all egress trials were accomplished with the palm-down hand-position (pronated). There were no significant differences in handhold preference between suited and unsuited conditions.

SUBJECT'S COMMENTS

While conducting exploratory research, many experimenters have been able to isolate problem areas, determine meanings of the experiment to the subjects, and depart upon new lines of study on the basis of a single remark by an observer or subject. Indeed, studies have often been completely overshadowed by the chance remark of a critical colleague.

The subjective data in this section were documented to suggest to the designer the subjects' orientation problems, their ideas of improving performance by adding hardware to the environment or by changing maneuvering techniques, and their observations of additional experimental variables. No attempt was made to integrate these excerpts, because they represent highly subjective opinions, and any attempt to explore the remarks systematically would require an independent study.

The excerpts were arbitrarily selected for their interest to the authors and listed in motion and posture categories. Unsuited (C1) and suited (C2) symbols were used to identify the subjects' clothing condition in cases where that information was recorded. All comments are direct quotations from the subjects or from the experiment monitors.

Egress, Headfirst

I felt that twisting my body during egress helped to bring my legs through the aperture. (C1)

While egressing face down, I would rotate my body without apparent thought.

I felt I stubbed my toe on every run. (C1)

Rolling through headfirst seemed to work much better. (C1)

The entry through the 19-inch hole with the headfirst, side-side is the difficult of the series, I believe. You have no place to launch once your body is approximately halfway through. You have to launch off the outside of the iris.*

On your headfirst, bottom-handhold entry you are restricted on your degree of launch. You can only pull yourself partial way through, you have to launch the rest of the way from the iris itself. (C1)

I think you do better by acting like a tumbler and coming out in more or less a somersault. (C1)

The headfirst, bottom-bottom (both hands on bottom handhold) appears to me to be about the best way to come out with a somersault. (C1)

*Asterisked comments were gathered from additional flights not flown for the primary study, but conducted to explore problems generated from the data of this report.

I do like the headfirst and hands on the bottom. I think you can come out a lot better that way. (C1)

In relation to the bottom-bottom, headfirst entry and exit, this is a lot more easier as you swing your body. You have a pivot point on each side by the two handholds in getting through and out from the exit is a little more difficult here for you don't have anything to launch from if your body is longitudinal with the exit as you are leaving it. (C2)

Headfirst, side-side appears to be the most complicated one to go through the exit. There is a fraction of a second there that your arms have to come back to your body in order to come through the opening at 20 inches (Monitor).*

I got hung, I got in a bind, my feet were on the bottom of the iris, my hands on the side. I couldn't straighten out and I couldn't bend over. (C1)

It would appear that small vertical handles placed low on the periphery of the exit would help guide the subject and make it possible to pull himself down. (C2)

I have had a couple of bad slashes on the back of my lower leg (calf) above the ankle. (C1)

Headfirst, side-side. Sailed right through large opening; it (the gravity condition) was obviously at zero, since I aimed at at the bottom and by the time I got to the iris I was already to the ceiling. I think this definitely shows the Coriolis effect. (C1)

With a large opening, one is not aware of or concerned with where his limbs are sailing. (C2)

Just aim for the bottom, you clear it just beautifully. (C1)

With the headfirst, side-side (handhold) and the middle-sized aperture, you don't twist your body or bend your body into an angle as you would if you grabbed the bottom and, therefore, you don't hook your toes or you don't arch your back so you catch the back pack on top of the iris. With the headfirst, side-handhold, I get about halfway through and my arms stop me. (C1)

Egress, Feetfirst

The egress that felt most natural was the one in which I went through feetfirst. (C1)

Leading with the feet meant that the shoulders were the last to go through and, therefore, the subject could maintain a stable relationship with his surroundings by holding on until the maneuver was completed. (Large

*See footnote on previous page.

aperture.) With a small aperture, the body has to be in a normally straight position in order to egress, and this does not allow observation of one's relationship to his surroundings.

This maneuver in the aircraft includes an artifact, in that naive subjects try to maintain their position to the cabin floor during and after egress, in order to prepare for the coming excessive gravity and this reorientation effort often introduces a twist to the egress motion. (Cl)

Attempts to go through feetfirst, face-up seem relatively easy, but not as easy or natural as headfirst.

On the feetfirst top-top with a 19-inch hole, your body is tilted to about a 35-degree angle on entry. Indeed, you have to straighten out your body to pass through the iris. (CI)

A feetfirst, side-side, I think you run into trouble on that due to having to swivel your arms too much. I like the feetfirst, top handhold but there again you run into trouble with your arms having to swivel. (C2)

In the pressurized condition, using the top handhold and coming through feetfirst, I find it a little difficult getting my toes up over the sill of the aperture. (C2)

Coming through handholds side-side (hand positions) feetfirst, plus one inch, about halfway through I seem to get stuck just as the iris had passed by armpits, tended to hang up on the inside of the arms. (C2)

I am very confident, feetfirst, that I don't get any impact with the iris; however, head first I have no knowledge of my feet and periodically I bang them. (Cl)

Feetfirst, top handholds, I almost inadvertantly grabbed the side handholds. Apparently it must be something natural about wanting to grab the side handholds going through feet first although its been my experience that when I do go up to the top (handhold) I get through a lot easier but apparently there's a natural impulse to go to the side (handholds). (C2)

The side-side (handholds) feet first is not a particularly easy way to to through the iris especially when it's as small as it is. I found I had to let loose of the handholds as soon as I get my feet through and then grabbed the iris from above. I think its much easier when going through feetfirst to use the bar that's above the iris. (C2)

I prefer a slightly smaller iris than the medium size, because with a larger opening I don't concentrate on where my limbs are and as a result my legs are getting some bad bruises on the calf from the upper part of the iris. (Cl)

When I go through the iris, I'm going to want to know where I'm going therefore I sort of tip my head so I keep a field of vision. In so doing, my feet go toward the floor and often I catch my helmet. (C2)

Of the two methods of going through the iris, the feetfirst method seems to be a little easier although there is no difficulty in either headfirst or feetfirst egress under lunar G. Under zero G, the problem is not one of getting through the iris but one of getting to your seat after you get through. (C2)

The natural tendency is to shoot toward the floor, which I did, and therefore I seem to strike the top of my helmet. (C2)

Once my body was halfway through, I switched from the side handhold to an upper handhold to guide myself to seat No. 2. (C1)

Soaring

Soaring from bulkhead through the opening creates a problem in alignment, due to Coriolis effect and turbulence. (C1)*

Soaring proved difficult due to turbulence; a cone-shaped funnel approach would be helpful. (C1)

The aperture height from the floor seemed too convenient; this should be varied. (C1)

With the foot launch, you have more speed to get to the hole, and to get through it into the other side from a sitting position, even on the floor, is better than the seat. (C1)

On getting to the seat from the exit, a half-turn, bodywise, in either direction will have you in a seating position for landing in the seat or close to it. (C1)

I was surprised at how easily you can get skinned on the metal going through the iris, and how helpless you are once you leave the iris. I seem to be doing a lot of needless oscillating, once I leave the iris. (C1)

Once I get through the iris and push off the bottom of the iris, it makes me go up towards the ceiling so that I miss the seat and I end up floating directly above the seat. (C1)

I hit the ceiling with good force and twisted one of my fingers. (C1)

When I tried to shoot for the seat, I must have shot too hard, probably with my right hand; therefore, I forced one side over and hit the seat in a side fashion. I just couldn't control my body on that particular run. (C1)

Twisting on the ceiling, then shooting myself toward the chair in a backward fashion, is a good technique. (C1)

It really helps if I drag my toes along the floor, keeping in contact, and keeping orientation. (C2)

*See footnote on page 20.

The big thing after going through the iris is the disorientation that one has or, anyway, that I have; especially since I really don't remember what the heck's going on and it feels like I have my eyes closed and I'm sure I don't.

This area was a disoriented affair, with problems of deriving benefit from feet and getting in chair—lack of directional propelling force to guide into chair. (C2)

Tethering*

Pulling a subject through the opening on a tether line seems easy, provided the person towing line is secure. (C1)

A subject can pull himself through an opening on a tether line by hand over hand, although oscillation does occur. (C1)

Pulling a subject through the aperture by means of cord resulted in subject's body rotation, forward and downward. (C1)

Handling Of Injured Personnel*

Stuffing a limp body through the aperture seems relatively easy to accomplish. (C1)

A person reaching through the opening and pulling a subject back through appears feasible, however, it seems time consuming for the person to orient the subject to a position in which he would fit through the opening. (C1)

Sitting

Sitting is becoming easier now, as you turn your body and are in a sitting position when you hit the seat. (C2)

I seemed to be hovering over the seat and could not get a handhold to bring myself down. (C2)

When I hit seat No. 2, I try to hit it hard in order to stop the clock. (C1)

When I came out of the iris, I shot just a little bit too hard and caught my right leg under the chair; and as I twisted to turn to sit in the seat, I started to twist my ankle. I got it out in time, so no damage was done.

Taut tether lines or handholds on armrests of seat No. 2 would benefit the user. (C2)

Standing

*See footnote on page 20

I seemed to be getting a lot of negative (gravity force in the aircraft), but I could be mistaken. I might have been pushing off too hard initially, with my feet in getting to the exit. (C1)

I notice on the departure from seat No. 1 that I seem to be concentrating on a good handhold on the seat in order to obtain a good departure. I seem to do much better if I concentrate on holding my feet together and if I position my body carefully before pulling on the handholds and also aiming for seat No. 2 before pulling on the handholds so that I can get a direct flight to the seat. (C1)

This must have been zero (gravity) because once I started to push myself from the seat, my feet sailed up and I hit my right leg against the upper side of the iris. (C1)

Getting from the seat to the iris is no problem. I just merely hook my legs underneath the chair as we go into the maneuver and then, once we hit zero G, I drag my toes across the floor and just sort of wade toward the iris, grab the bars, and pull myself through. (C2)

General

In a zero G, you have to be real careful, about banging your head on the ceiling but up until now I can think of no difficulties in going through; it is just the matter of getting your arms turned in the right direction when you go through a hole. (C1)

On the small openings, the handhold should be located a little closer to the opening; that way, my arms would not be bruised going through. (C1)

With the suit on, you are so restricted; your mobility is restricted as you can't maintain flexibility of your body. (C2)

On approximately the eleventh run, I began to feel very uncomfortable when the suit was pressurized. I complained that the suit was being filled to a higher pressure than normal (perhaps a fatigue symptom). The monitor noticed that I was getting clumsy on getting to the seat. Heat may be a factor in the problem. (C2)

I can't really tell the difference between lunar G and zero G. (C1)

You don't overshoot the seat at 1/6 G—it's easier to get to the seat at 1/6 G. (C1)

I feel that there is definitely a learning factor.

I enjoy the inflation portion of the run, because it's the coolest. (C2)

I had problems, because I aimed for the center rather than the bottom of the iris. (C2)

I can see right now that you're really gonna have to fight this suit to make it through in time (11th run). (C2)

Lunar G tends to pull your feet down. (C2)

I can see the zero-G runs are going to be harder; as soon as you leave your seat, you tend to float up. (C2)

In each case, I definitely think of grabbing a particular handhold as being my first object, and then worry about the rest of the maneuver after that (C1)

There doesn't seem to be any way to propel from the iris to seat No. 2. Handholds would help. (C1)

I don't really seem to have any feel or sense for the positioning of my legs.

Feetfirst, top-top; feetfirst, side-side; headfirst, bottom-bottom; headfirst, side-side is my order of preference, for ease. (C1)

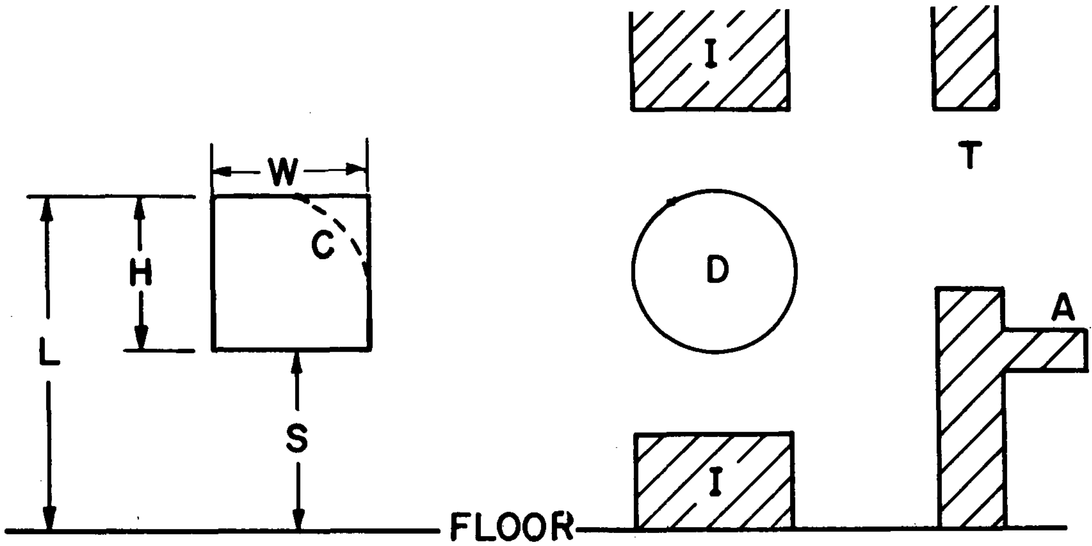
SECTION IV

IMPLICATIONS FOR DESIGN

The problems of rapid evacuation have arisen in designing doors in bulkheads of naval ships and submarines, buses, missile ground support trailers, trains, rocket test installations and chemical plants. Some of the significant factors in these problems, such as body dimensions, frequency of need, available time for exit and physical design limitations, may become highly critical when designing exits for minimum weight and space requirements of space vehicles (ref 2).

LITERATURE REVIEW

A review of aircraft evacuation literature yielded the dimensions that influence 1-G egress behavior. Figure 25 summarizes these dimensions and charts standard minimum areas. These standards were evolved from studies of lightly-clothed personnel evacuating vehicles under normal gravity conditions, and were highly related to a standup, walk-through type of evacuation.

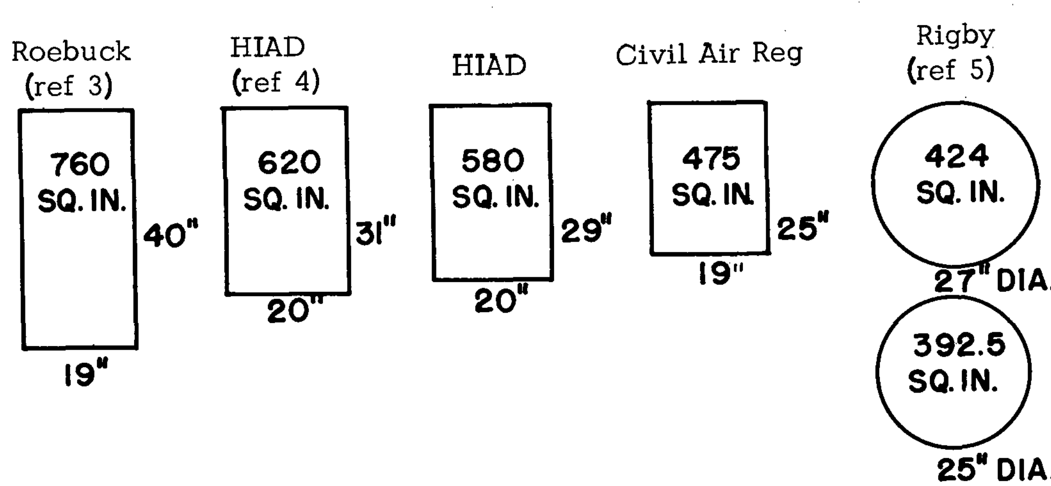


DIMENSIONS

H HEIGHT OF OPENING
L HEIGHT OF LINTEL
S HEIGHT OF SILL
W WIDTH OF OPENING
C CORNER RADIUS

D DIAMETER
T THICKNESS
I INTERFERENCE
A AUXILIARY STEP (OUTSIDE)

EXIT DIMENSIONS



STANDARD MINIMUM EXIT AREAS

Figure 25. Standard Minimum Exit Areas and Dimensions

Roebuck (ref 3) summarizes the effects of these dimensions on evacuation time:

> "H* is approximately equal to the sum of chest and thigh thickness, about as small as one can compress the body in a hurdle position before it is necessary to change to a crawling position. After L becomes greater than body stature, little further change in time is expected. H depends upon L, if L is fixed, increasing H will improve performance . . . ."
>
> "The effect of W is not a major problem in present aircraft design. The 19 or 20 inches required to eliminate most of the restrictive effects of width is readily achieved between conventional frame spacing . . . ."
>
> "S can have a pronounced effect on exit time. Time varies little as S increases up to approximately 25 inches, but it rises in an accelerated manner thereafter. It is not possible to distinguish accurately between the effects of step up and step down. S is generally less important on larger openings . . . ."
>
> "The effect of Slant (slant of A, fig 25) was to give extra impetus to the subject, but was only effective on the locations lower than the optimum height for a horizontal step (over 36 inches). . . ."
>
> "Seats (I) below the exit may be an interference for low S, but an aid to high S. Excape time is essentially that for 'seat clear' conditions until the seat cushion extends across about half of W. A marked difficulty was experienced with combinations of berths and A. It is definitely an awkward configuration . . . ."
>
> "C limits are necessary only on small exits . . . ."
>
> "The important factors are S, H, W, and I."

Randall suggests the following general factors for establishing workspace requirements (ref 6):

> "Inclusive dimensions (passageways, accesses, etc) which must accomodate or allow passage of the body should be based upon the 95th-percentile values."
>
> "Exclusive dimensions (reaching distance, control movement, etc) which prohibit or are limited by extension of the body should be based upon the 5th-percentile values."
>
> "Fixed features (controls, displays, handrails) should be located in accordance with appropriate mean values to provide utility to the full range of anthropometric variation."

*The authors substituted contractions (H, W, etc) in Roebuck's excerpts.

"Adjustable features (seats, belts, controls, etc) should be adjusted from the range from 1st to 99th in each critical dimension. Trade-offs, Percentile increments should not be used as design tradeoffs. Tradeoffs may be made along alternative tasks or body positions, but the final design should generally accommodate the 5th to 95th percentiles."

The authors were faced with the problem of relating existing standard areas based on 1-G walking, stepping, and climbing performance to area requirements for zero-G performance. Simons and Gardner (ref 7) have shown that surface-free motion behavior differs markedly from earthbound behavior, and the authors were faced with the problem of relating existing standard areas to area requirements for zero-G and fractional G performance.

The weightless body is predominatly an open-chain system of links. The links rotate about joint centers and exhibit a variety of angular positions consistent with the range of motions permitted by the joints before restraining mechanisms impose limits. An open-chain system cannot produce determinate or strictly predictable motions. The end member may have an infinite number of positions relative to the trunk allowed by the cumulative range of the more proximal joints (ref 8). Even though a segment may be placed at a variety of point positions in space (Dempster (ref 8) asserts that body activity is infinitely variable), there appears to be a cumulative pattern of motions since most line movements are rotational rather than translatory, relative to the center of mass of the body.

Although the entire mechanism can be crudely described in terms of the conservation of angular momentum, principles of mechanics are only partially helpful, since the relative motions of the segments depend also upon the energy relationships of the muscle groups during a motion transition.

Roebuck's (ref 3) minimum exit area was the only area experimentally related to exit time; however, his egress motion was based on an upright posture and cannot be realistically related to our soaring posture.

DESIGN PROPOSALS.

Our design proposals utilize Roebuck's mockup approach, wherein the experimental data are presented in the form of a "Product or position rather than measurement of people." In effect, the designer is told how much the machine would have to vary to properly fit the desired percentage of persons. As Roebuck suggests, "the classic anthropometric points and distances should be included with data establishing body position in space and coordinates of surfaces of possible contact with the environment." King (ref 9) recognized that "what was needed was a set of curves giving effects of changes in exit dimension on exit time."

In the mockup approach, one measures the restrictions imposed on a measured group of individuals selected to fit points on the expected distribution. The data can then be extrapolated to fit the desired range of percentiles, which leads to a precise indication of space requirements. Confidence can be placed in the results, because both theoretical and practical aspects have been explored under controlled conditions.

Shoulder Plane

An arbitrary elliptical baseline called the shoulder plane was established for relating the body dimensions to exit clearance, based on Roebuck's observation that "the height of an opening dramatically illustrates that there is a smallest opening through which one cannot pass at all." The shoulder plane represents the, chest depth and shoulder breadth of the 95th-percentile, nude Air Force man (ref 8). See table II and figure 26. Since the major axis of the ellipse is 19.4 inches, this dimension is considered the minimum for any shape and serves as a datum reference equal to 1 in figure 27.

TABLE II

CHEST AND SHOULDER MEASUREMENTS

Percentile	Shoulder Cir (Inches)	Chest Depth (Inches)	Shoulder Breadth (Inches)
95%	49.4	10.4	19.4
50%	45.1	9.0	17.9
5%	41.6	8.0	16.5
Range: 5% to 95%	7.8	2.4	2.9

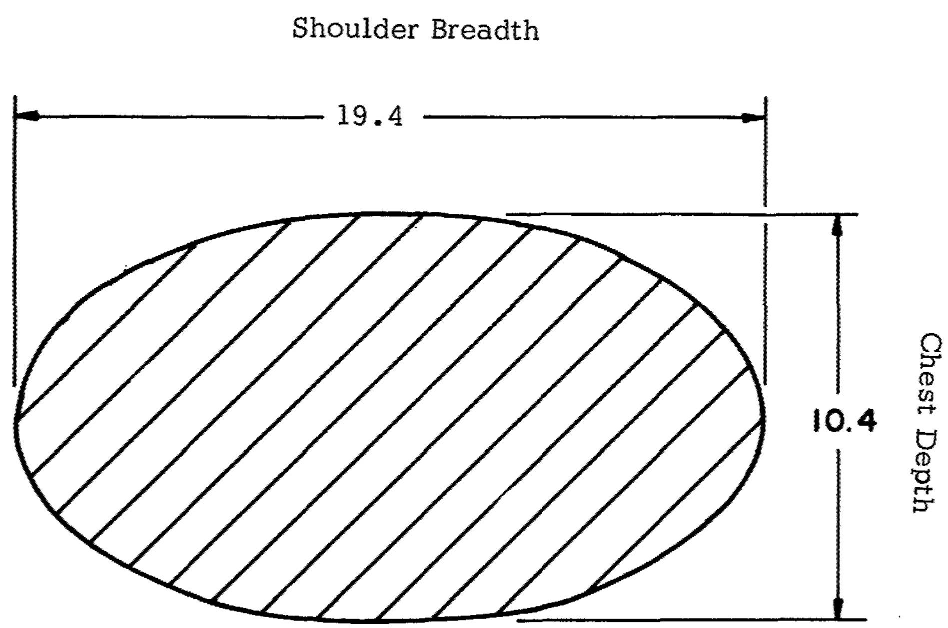


Figure 26. Shoulder Plane

Figure 27 congruently expanded various shapes as they were related to the basic width of 19.4 inches (Appendix II). For example, an expansion factor of 2 represents a width expansion twice the width of a man sliced through the shoulders, or 38.8 inches. Applying an efficiency criterion of minimum width, the most efficient shapes were the ellipse, rectangle, tilted square, circle, and square in descending order.

Sweeney had earlier related these shapes to the shoulder plane area (figures 32 and 33). Applying an efficiency criteria of minimum area, he found the most efficient shapes were the square, circle, rectangle, and ellipse in descending order. His charts are not pertinent to this study, because the major axis of the plane did not traverse all of the shapes; however, the area derivations may be of interest to the designer considering the egress problems of symmetrical or flexible masses.

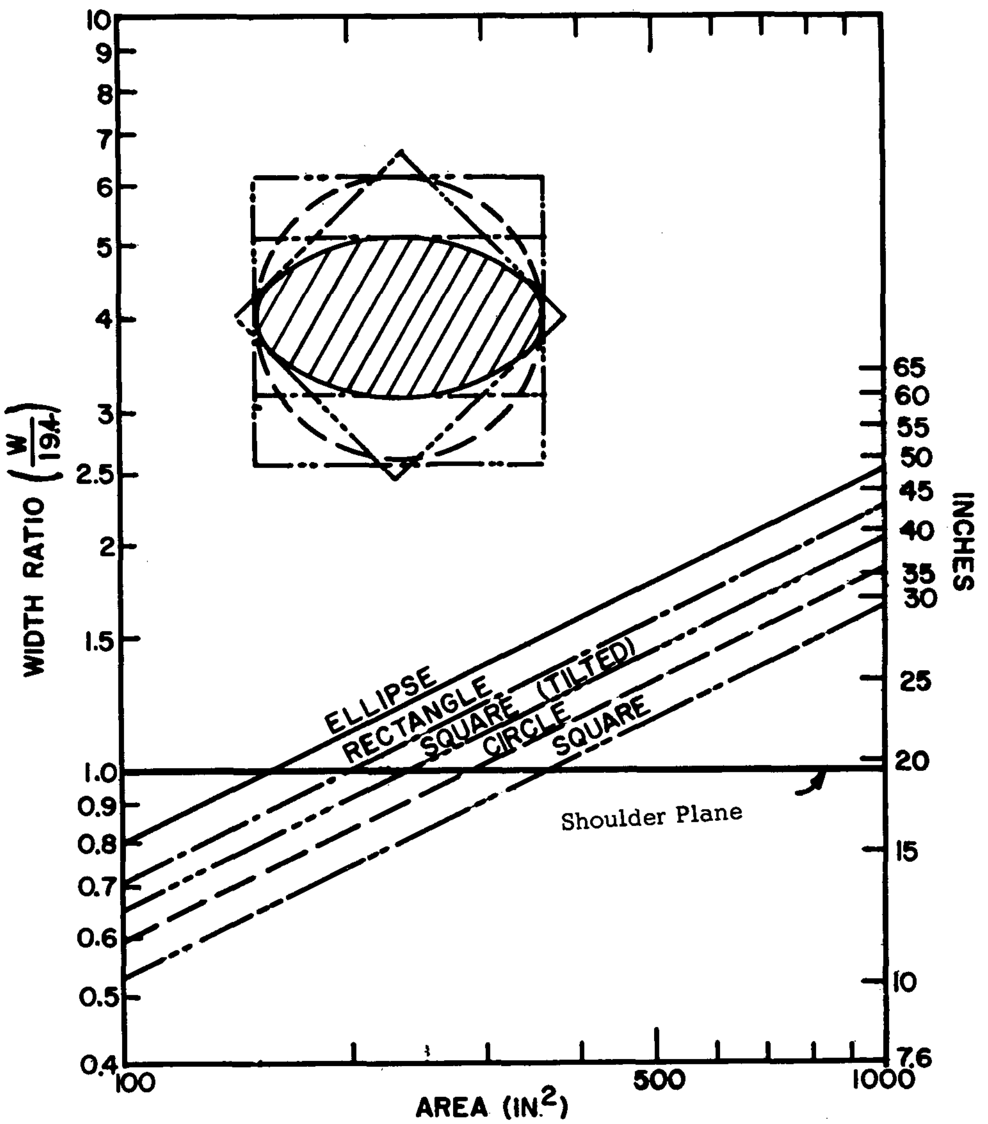


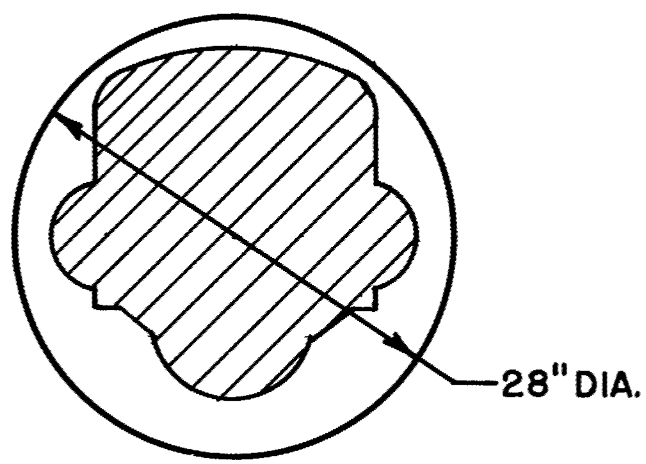
Figure 27. Congruent Expansion of Four Shapes Equated for Width

Addition of Mass

Necessary inspection, supply, maintenance and assembly functions will require an orbital worker to carry many devices. The mass of these devices should be added in such a manner as not to further restrict his motions or even perhaps, to enhance his motion potential under low gravity conditions. A study of motions and maneuvers with masses added systematically to the worker may indicate new and unusual motion-mass-volume relationships.

Egress behavior can be sharply influenced by the size and mass of a man's gear. A maximum exit area may be necessary for a longitudinal body transfer by an orbital maintenance operator wearing an inflated full-pressure suit and self-maneuvering unit (SMU). Griffin (ref 10) estimates the minimum clearance for this system to be approximately 28 inches (see figure 28); however, his dimension does not provide for limb manipulation, eg, "without better definition of the present suit to be employed, it is safe to say that a suited man wearing the self-maneuvering pack can pass within a 28-inch-diameter hatch. The degree of arm and leg mobility within this diameter, however, will undoubtedly be extremely limited."

Operator with SMU



Cross Section of SMU and Operator

Figure 28. Egress With Self-Maneuvering Unit (SMU)

On a separate flight, three unsuited subjects egressed a 21-inch (width) by 23-inch (height) rectangular opening while wearing a model of the Self-Maneuvering Unit (SMU). The following information was obtained:

Headfirst runs were easy with few contacts; chest control box was prime interference point. Feetfirst runs were largely unsuccessful; subjects could not judge position of bottom of unit; a control box hangup did, accidentally, rotate the subject perfectly through the exit. Torso bends were still possible because of the retention of leg mobility. Subjects appear front-oriented, being concerned with chest rather than back clearance, for example, "If you keep as low as possible and watch your front there doesn't seem to be any trouble." One subject was momentarily hung with his toes and said he still maintained complete body control. The shoulder pads were not tight enough for most subjects. Under 2-1/2 G, it was noticed that there was no back support, "only shoulder and butt contacts."

Feetfirst maneuvers can cause troublesome backpack hangups; headfirst maneuvers may be easier if the mass is distributed across the chest. For egress considerations, any addition of mass to the man should consider the shoulder plane and its width relationships to other shapes (figure 27). If the mass can be added in such a manner that the major axis of the shoulder plane is retained as the largest dimension, egress time should not be unduly lengthened.

Mobility Indices

Data from future studies of motion-gravity relationships could be presented in the following manner (see figure 29):

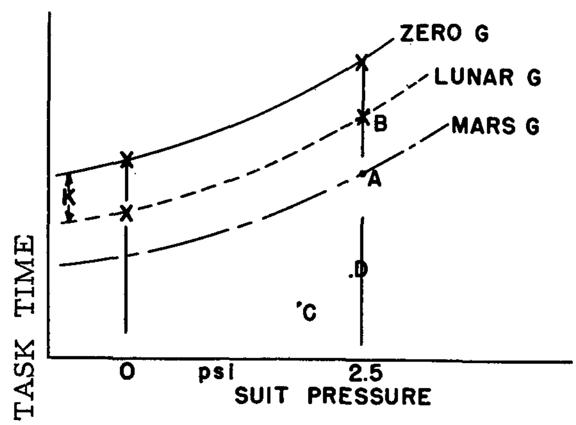


Figure 29. Motion-Gravity Relationships

Such a presentation might be used to relate and graph the following functions:

- <u>Rating Restraint Systems</u> - The total motion retardation of various systems (pressure suits, back packs, tethers) could be measured and rated with a single time unit.

● Task Analyses of Motions - Time constants can be plotted between motions and gravities. For example, time K should be added for the operator performing under zero G as compared with lunar G. A specific motion analysis might show that a specific lunar therblig (discrete motion) requires a discrete constant when plotting between gravity and suited conditions.

● Time X Pressure Tradeoffs - Normally the restraint condition remains a fixed variable; however, it is conceivable that the designer may have a choice of motion retardation systems. For example, how much time does system C differ from system D?

● Ease of Performance and Energy Expenditure Indices - Does a task requiring more time require more energy expenditure? For example, would identical motions require more or less energy under different gravity conditions?

● Gravity X Time Tradeoffs - What is the overall time difference between performing a task on the moon (B) and on Mars (A) with the same suit? What are the specific motions that account for this difference? Answers to the latter question would require data for each motion for each gravity.

An overall mobility index could represent an accumulation of arbitarily weighted time scores for selected motions. A more meaningful presentation should include more data points such as Mars, Neptune, and Earth gravities; suited-uninflated, 3.5 and 5 psi inflation levels, and more motions with more hardware including tunnels, ladders, handholds, etc.

SECTION V

FUTURE RESEARCH

The purpose of this report was to determine the differences in motion behavior between suited and unsuited subjects under low gravity conditions. The research aircraft defined the test volume and the authors arbitarily inserted a few motions and hardware structures within that volume. This section discusses other motions and hardware aids that appear worthy of future study.

In April 1963, the nine NASA Gemini/Apollo astronants were indoctrinated with zero-G procedures in the KC-135. Four of them also flew with the authors in the C131B to help isolate motions that may be pertinent to the Apollo mission. The workspace in the C131B was structured with an adjustable tunnel, mainly to stimulate the subjects' imagination. Figure 30 shows some of the tasks accomplished during these flights, and the following paragraphs discuss motion and volume requirements that appear to be profitable areas for research:

MATERIAL HANDLING AT LUNAR G

In a study analyzing the problems of transporting, lifting and positioning

large masses, rules of thumb for handling masses could be developed. For example, a test subject (figure 30A), while carrying two of the authors, swung his charges near the end of his walk, successfully redirecting his path of locomotion in spite of his increased momentum and low frictional qualities. The subject mentioned, as a troublesome factor, the difficulty of encircling large masses with the suited arm.

LONG LINE HANDLING AT ZERO G

A study was made of the use of a flexible line as an aid to locomotion and self-rotation. The test subject found that he could minimize his pitch oscillation by pulling with rigid wrists, and by employing smooth, rather than jerky, arm motions and very short distances between handgrips (figure 30E). He further mentioned a preference for a taut line.

SUIT MOBILITY AND LUNAR WALKING

A study of the affect of suit design and inflation levels on lunar locomotion was performed. One subject suggested that suit mobility has a significant effect on the gait - "moments generated within the suit can cause extra corrections, and pressure suit mobility was main drawback during whole maneuver (figure 30B)."

FIXED MASS ADDED TO THE LUNAR WORKER

A study was done analyzing the effect of systematically adding masses of various sizes to the operator. A test subject noted his increased pendulous behavior and poorer starting and stopping qualities when he carried an equivalent weight on his back (figure 30C).

EGRESS MOTION - VOLUME RELATIONSHIPS

By replacing the iris with an adjustable tunnel (figure 30D), the effect of changes of volume on egress time and technique can be studied. One subject suggested adding recessed handholds or a rope within the structure, and supposed that a longer tunnel (ours was 5 foot in length) would cause more extensive motion restrictions because of the entry motion covering much of the present tunnel distance. Another subject suggested VelCro® paths in the tunnel, with matching fabric on the glove palm or toes of boots. Another subject noted that body-to-tunnel position and alignment can be a significant factor before egress. For example, he found that in standing too close to the tunnel, he increased rather than decreased his egress time.

LADDER LOCOMOTION AT LUNAR G

A brief study was made to determine optimum inter-rung distances for a ladder to be used in subgravity environments. A pilot zero-G study has shown that there is only a 20% increase in time, compared with 1-G, when a person goes "down" a ladder having alternate spokes 12 inches apart (figure 30F).

HANDHOLD DESIGN AND PLACEMENT FOR ZERO—AND LUNAR-G CONDITIONS

A study was made of the configuration and location of handholds based upon a spatial analysis of suited-motion performance. The handholds should be omnidirectionally configured (approachable from any direction), and their separation distance should yield a minimum of pitch oscillation to the user. One subject suggested that puncture of the suit should be a crucial consideration (nonprotruding handholds)—"our movements should be slow and considered" —and another subject commented that proper handhold placement may be the minimum structure for defining space requirements.

STANDING AND SITTING AT ZERO—AND LUNAR—G

The development of simple chair hardware for aiding the operator was considered. The subject noticed that he could not sit without a handhold or stand without leaving the surface during zero G unless someone held his feet to the floor.

CRAWLING DURING LUNAR G

A comparison of time scores between suited and unsuited conditions was made. The subject noticed that it was impractical to crawl during zero G unless a monitor held him against the surface. A new type of crawl with different arm-leg motion relationships may be natural at lunar G. Such a motion may be of crucial importance to the injured lunar worker.

TECHNIQUES AND TETHERED FLIGHT PATHS FOR CONTROLLED SOARING DURING ZERO G

Hardware aids (harnesses, lines), soaring techniques, and charts of tethered flight paths for performing nonrotating, single-impulse transfers were developed. The subject was surprised when he "got a tremendous push with my feet!" Perret (unpublished) charted one of the pendulous tethered flight paths of the soarer and Mueller and Simons (ref 11) have indicated the almost fantastic flight paths available to the tethered free-floater. Each of the three study phases could be independently studied and reported.

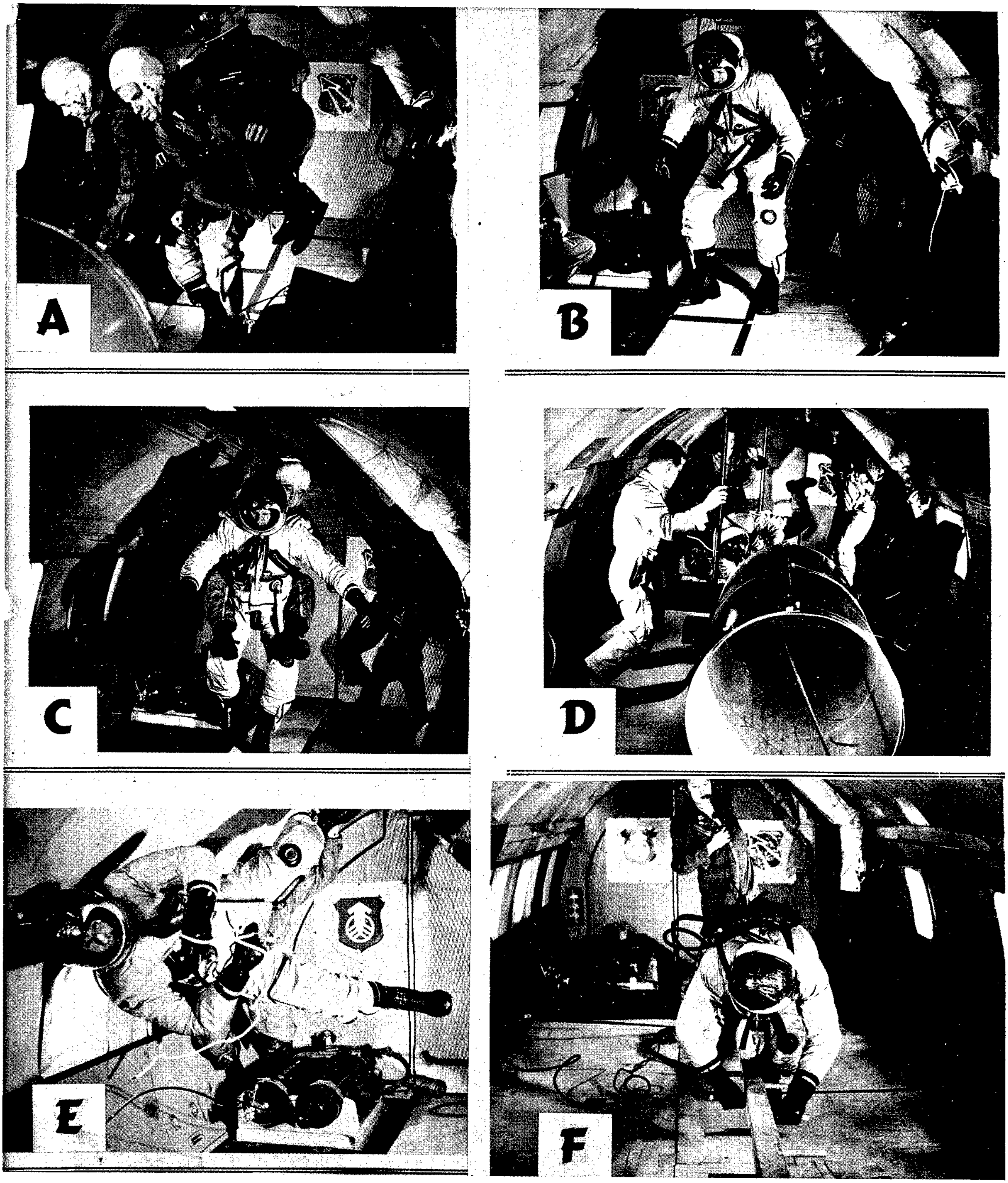


Figure 30. Problem Search Activities

OPERATION OF HATCHES DURING ZERO—, AND LUNAR—G CONDITIONS

A study was made of ingress and egress techniques, torque requirements, body positions, hardware aids (handholds), and bulkhead designs. One subject suggests that such devices as the Apollo and Lunar Excursion Module (LEM) airlocks be evaluated for opening and closing factors with the volumes under pressurized and unpressurized conditions and the operator wearing and not wearing portable life support equipment.

TOTAL CREW PERFORMANCE UNDER ZERO—, AND LUNAR—G CONDITIONS

The opportunity for exploring team performance in a large volume aircraft for such a complex crewspace as the command module of the Apollo vehicle was emphasized by the astronauts. Such factors as component shape and placement, normal and emergency intergroup motions within, through and upon the vehicle, and crew training with actual equipment can be studied for motion problems and hardware fixes and indicate motions capable of comprehensive analyses under several suit and gravity conditions.

SECTION VI

SUMMARY AND CONCLUSIONS

The motions of unsuited and pressure-suited subjects performing lunging, egressing, and landing tasks under zero- and lunar-gravity conditions were studied. The subjects were timed and filmed during the trials, and interviewed after each trial as they accomplished the motions during the weightless and lunar gravity maneuvers of a large cabin aircraft. Performance data are presented for various combinations of clothing, gravity, and body position conditions. Time and contact data are presented for the egress motion as it is influenced by changes in exit area. Orientation problems and maneuvering techniques as influenced by area and volume restrictions are discussed.

TIME SCORES

Suited motions required approximately 30% more time than unsuited motions for both gravity levels.

All motions required approximately 35% more time during zero gravity than during lunar gravity. Zero gravity required approximately 30% more time than lunar gravity under unsuited conditions and 40% more time under suited conditions.

The headfirst-bottom handhold position proved to be the quickest approach, egress and landing technique. The feetfirst-side handhold position was the slowest. There was no appreciable difference between a headfirst-side handhold and a footfirst-top handhold egress technique

Egress time was inversely related to the exit clearance dimension. Five inches of exit clearance improved egress time by approximately 6%.

Soaring, landing and sitting required 45% more time for the unsuited subject and 54% more time for the suited subject under zero-G conditions than under lunar G conditions. Zero gravity tended to increase the total mobility of the subject compared to earth gravity but overcontrol and limb freedom retarded his task performance.

NEW MOTIONS

A 1-G approach motion would normally consist of standup, walk, grasp, pull and step motions. During low-gravity conditions, these fairly discrete motions were replaced with a smooth seat-launched lunge. The resulting floating of the subject allowed retention of the seated posture for a feetfirst approach.

A 1-G egress task would require steps and climbing motions. These independent motions in a 1-G environment were replaced by continuous motion made possible by low-gravity conditions, resulting in a saving of time and effort.

A 1-G landing motion would probably require less time and would consist of walking, turning and sitting motions. The unaided soarer experienced flailing movements in attempts to return to the surface. Soaring motions during landings required 50% more time during zero G than during lunar G which suggests the relative helplessness of a flailing, suited subject arriving at a surface. Arriving at a surface feet first without a handhold required 20% more time than with the headfirst soar. Arriving at his seat, the suited subject had noticeable difficulty in attaining and maintaining a seated posture. The suited operator required 33% more time than unsuited operator, and zero G required 20% more time than lunar gravity for the landing motion.

There is a good reason to suspect that man will choose many new motions for performing other tasks in low-gravity environments.

CONTACT SCORES

Contact with the exit area was made twice as often in the suited condition as compared to the unsuited condition. The subjects contacted the iris twice as often with a 1-inch clearance than with a 10-inch clearance. The subjects struck the edge of the iris most often when using the headfirst-side handhold technique and made fewer contacts when using the headfirst-bottom handhold technique. Subjects who egressed feetfirst made still fewer contacts, using either top or side handholds. The feetfirst approach resulted in half as many contacts as the headfirst approach. The same order of exit method success held true for both suited and unsuited subjects.

Accuracy of motion within the environment rather than time of motion appeared to be a more sensitive measure of operator performance for the egress motion.

Performance curves for new motions and gravities were proposed as an approach for relating various restraints to single time units (mobility indices).

A 95th percentile shoulder plane with a 40.3 cm (19.4 inches) axis was proposed as a basic egress reference, and this shape was related to the congruent expansion of four exit-area designs.

Limitations of the present study were noted by subjective comment of the subjects and new studies were proposed involving more motions, gravities and volume structure.

LIST OF REFERENCES

1. Hammer, L. R., Aeronautical Systems Division Studies in Weightlessness: 1959-1960, WADD Technical Report 60-715, AD 273 098, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, December 1961.

2. Aircraft Emergency Evacuation: A Method for Evaluating Devices Procedures and Exit Provisions, US Dept of Commerce, CAA, Office of Aviation Safety, Washington, D. C., April 1951.

3. Roebuck, J. A., Jr., and B. H. Levedahl, "Aircraft Ground Emergency Exit Design Considerations," Human Factors 3, September 1961.

4. Handbook of Instructions for Aircraft Designers (HIAD), Vol III, AFSCM 80-1, Research and Technology Division, Wright-Patterson Air Force Base, Ohio.

5. Rigby, L. V., J. I. Cooper, and W. A. Spickard, Guide to Integrated System Design for Maintainability, ASD Technical Report 61-424, AD 271 477, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, October 1961.

6. Randall, Damon, Benton, Patt, Human Body Size in Military Aircraft and Personal Equipment, AAF Technical Report 5501, Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio, June 1946.

7. Simons, J. C., and M. S. Gardner, Weightless Man: A Survey of Sensations and Performance While Free-Floating, MRL Technical Documentary Report-62-114, AD 410 767, Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio, March 1963.

8. Dempster, W. T., The Anthropometry of Body Action, WADD Technical Report 60-18, AD 234 005, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, January 1960.

9. King, B. G., "Elimination of Some Time Losses in Emergency Evacuation of Passengers from Airplanes," Aeronautical Engineering Review 12 No. 3, March 1953.

10. Griffin, J. B., Feasibility of a Self-Maneuvering Unit for Orbital Maintenance Workers, ASD Technical Documentary Report 62-278, AD 287 053, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, December 1961.

11. Mueller, D. D., J. C. Simons, Weightless Man: Single-Impulse Trajectories for Orbital Workers, AMRL Technical Documentary Report 62-103, AD 289 257, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, September 1962.

BIBLIOGRAPHY

Aircraft Emergency Evacuation: Convair 240, Experimental Trials of Emergency Escape with American Airlines, Inc., Report No. 3, US Dept of Commerce, CAA, Office of Aviation Safety, Washington, D. C., August 1952.

Aircraft Emergency Evacuation: Trials of Emergency Escape from the Pan American World Airways Boeing 377, Report No. 5, US Dept of Commerce, CAA, Office of Aviation Safety, Washington, D. C., August 1952.

Aircraft Emergency Evacuation: Trials of Emergency Escape from the Trans World Airlines Lockheed 749, Report No. 6, US Dept of Commerce, CAA, Office of Aviation Safety, Washington, D. C., September 1952.

A Report of Results and Conclusions from Tests on the Effect of Size of Doors and Windows on Emergency Escape Time, Preliminary Report, George Washington University and CAA-CAB Subcommittee, Report No. 4, Washington, D. C., September 1951.

King, B. G., Aircraft Evacuation Under Fire Conditions, Medical Division, US Dept of Commerce, CAA, Office of Aviation Safety, Washington, D. C.

King, B. G., R. Ostrich, and M. C. Richardson, Emergency Escape Procedures, (A Report of Joint Studies with MATS and CAA on the C-124 and Supplementary Data, CAA, Office of Aviation Safety), AFCRC-Technical Report-54-56, Operational Application Laboratory, AF Cambridge Research Center, Bolling Air Force Base, Washington 25, D. C.

Lindquist, E. F., Design and Analysis of Experiments in Psychology and Education, p 292ff, Houghton Mifflin, Boston, 1953.

Weiss, Robert, Display Systems for Sub-and Zero-Gravity Flight, AMRL-Technical Documentary Report-63-11, AD 402 382, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, January 1963.

Hertzberg, H. T. E., G. S. Daniels, Anthropometry of Flying Personnel - 1950, WADC Technical Report 52-321, AD 479 53, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, September 1954.

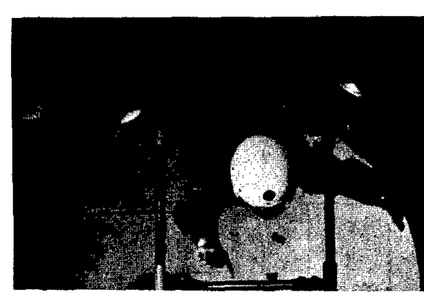
APPENDIX I

Pilot Study

A pilot study was conducted to select the independent variables and levels. A scaffolding constructed of 2-inch OD aluminum tubing was erected in the free-float area as shown in figure 31.

A

B



C

Figure 31. Egress Maneuvers

The adjustable rectangular framework was used as the exit and also offered firm grasping capabilities with orthogonally related handholds. The three authors performed "unsuited" egress maneuvers for three flights, and the variables were jointly selected from their pooled observations.

They tried nine position-handhold configurations and independently rank-ordered them for personal preference. The first four configurations were selected for the prime study.

They were frequently unable to complete the maneuver with less than a 1-inch shoulder tolerance. Thus a 1-inch tolerance was selected as the minimum hole width to insure the probability of completed maneuvers within the 12 to 14-second weightless period.

When using handholds greater than shoulder width +10 inches apart they tended toward an awkward use of the widespread handholds and oscillated excessively during the egress. The +5-inch tolerance was arbitrarily chosen as a midpoint for the +1 to +10 inch iris clearance scale.

Distance between handholds was not included as a variable because of the incapability of quickly changing the hardware between parabolas, and the addition of this variable would lengthen the already extensive experimental design. The handholds were set at 31 inches for the prime study to accommodate 95% of the population (inflated shoulder width plus 10 inches) and were centered upon and placed adjacent to the iris.

APPENDIX II

CONGRUENT EXPANSION OF FOUR SHAPES EQUATED FOR WIDTH

Philip Kulwicki
Behavioral Sciences Laboratory
Aerospace Medical Research Laboratories

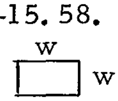
This appendix outlines the formulation of the congruent expansion curves for four common geometric shapes equated for width (figure 27). The initial area for each shape was constructed such that no part of the shape would enter the oval of the cross section of the 95th-percentile man. A quantity called the width ratio was based on the ratio of the width (long dimension) of each typical area to the initial width of the 95th-percentile man.

This concept works well for all minimum areas, such that the width of the area equals the width of the 95th-percentile man. Unfortunately, this equality is not characteristic of all geometrical configurations, notably an equal-sided polyhedron. The one case of this type considered in figure 27 is a square, tilted forty-five degrees from the horizontal.

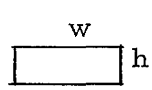
The diagonal of the square is longer than the major axis of the ellipse that it encloses. For this case, the width ratio cannot be $W \div 19.4$ unless we redefine W or 19.4. What is desired is to make the width ratio of 1 correspond to the exit area just enclosing the ellipse of the 95th-percentile man.

If it is assumed that the oval of the 95th-percentile man is approximately equal to the shape of an ellipse, the question then arises as to what to use as a reference on the exit area itself. Since the side of the rectangle was chosen previously, the side of the square may be chosen now. The width ratio is now width $\div$ initial width and the problem remaining is to find the length of a side of this minimim area canted square. The geometry of this problem is worked out below, from which we find for this canted square the width ratio equal to width $\div$ 15.58.

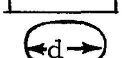
Areas of a square = w^2



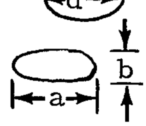
Area of rectangle = wh



Area of circle = $\frac{\pi d^2}{4}$

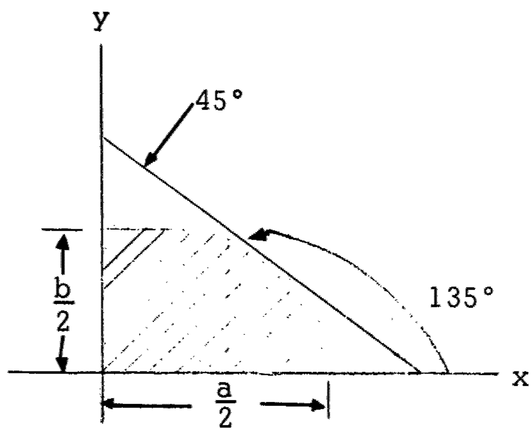


Area of ellipse = $\frac{\pi ab}{4}$



Constant ratio of height to width for congruent expansions is

$$\frac{h}{w} = \frac{b}{a} = .536$$



1. The equation for this ellipse is

$$\frac{4x^2}{a^2} + \frac{4y^2}{b^2} = 1$$

2. implicitly differentiating

$$\frac{8x}{a^2} + \frac{8y}{b^2}\frac{dy}{dx} = 0$$

or

$$\frac{dy}{dx} = -\frac{b^2}{a^2}\left(\frac{x}{y}\right)$$

3. the point under consideration is where

$$\frac{dy}{dx} = \tan 135^{\circ} = -1$$

4. substituting 3 into 2

$$-1 = -\frac{b^2}{a^2}\frac{x}{y} \text{ or}$$

$$y = \frac{b^2}{a^2}\,x$$

5. We know from 95th percentile data that

$$b = 10.4 \text{ in.}$$

$$a = 19.4 \text{ in.}$$

6. substituting 5 into 4 $\quad \frac{b^2}{a^2} = \frac{(10.4)^2}{(19.4)^2} = 0.2874$

$$y = 0.2874\, x$$

$$y^2 = 0.0826x^2$$

7. substituting 6 into 1

$$\frac{4x^2}{a^2} + \frac{4(0.0826x^2)}{b^2} = 1$$

$$x^2 \frac{4}{376.2} + \frac{0.3304}{108.1} = 1$$

$$x^2\ (0.0137) = 1$$

$$x^2 = 73.0$$

$$x = 8.544$$

8. From steps 6 and 7

$$y = (0.2874)x$$

$$y = (0.2873)\ (8.544)$$

$$y = 2.456$$

9. To find the y intercept (b), (= x intercept)

$$y = mx + b$$

$$y = (-1)x + b$$

$$2.456 = (-1)\ 8.544 + b$$

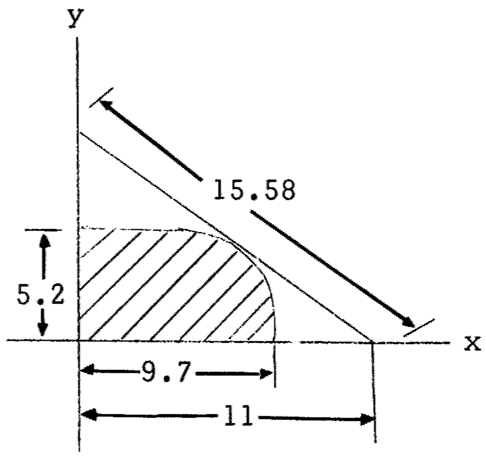
$$b = 11.00 \text{ inches}$$

10. Since the shape of the area is a square, the side of the square is equal to the step 9 times $\sqrt{2}$

$$\text{side} = \sqrt{2}\ (11.00)$$

$$\text{side} = 15.58 \text{ inches}$$

11. Therefore the width ratio becomes $\frac{w}{15.58}$



APPENDIX III

CONGRUENT EXPANSION OF FOUR SHAPES EQUATED FOR AREA

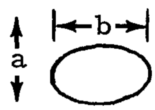
Timothy Sweeney
Behavioral Sciences Laboratory
Aerospace Medical Research Laboratories

This appendix outlines the formulation of the congruent expansion curves of four geometric areas equated for area (figure 32). The shoulder plane area of 158.5 inches squared with its chest depth to shoulder ratio of 11 (or 10.4) to 20 (or 19.4) was maintained for the rectangle and ellipse with

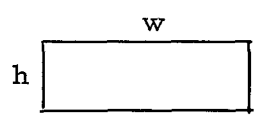
$$10.4/19.4 = .536$$

This proportion was maintained (congruent expansion) as size varied. With $\frac{h}{w} = .54$, the rectangle area was equal to hw or $.54w^2$. With $\frac{a}{b} = .54$, the elliptical area was equal to $\frac{\pi ab}{4}$ or $\frac{.54\pi b^2}{4}$. The square area was equal to s^2 and the circle area to $\frac{\pi d^2}{4}$. Logarithmic scales were chosen in order to yield straight line plots. The Area Ratio scale was fixed with the shoulder plane equal to 1 and all shape expansions equal to AR/158.5.

Derivation of figure 33, incongruent expansion of four shapes equated for area. The ellipse and rectangle can expand incongruently by varying proportion with size. This chart plots four expansions of the ellipse and rectangle with "a" and "h" curves plotted for 11, 15, 20 and 24 inches depths as shown below.



Ellipse



Rectangle

a = 11 in., AR = $\frac{11\pi b}{880}$	h = 11 in., AR = $\frac{11w}{220}$
a = 15 in., AR = $\frac{15\pi b}{880}$	h = 15 in., AR = $\frac{15w}{220}$
a = 20 in., AR = $\frac{20\pi b}{880}$	h = 20 in., AR = $\frac{w}{11}$
a = 24 in., AR = $\frac{24\pi b}{880}$	h = 24 in., AR = $\frac{24w}{220}$

The Area Ratio scale was derived in the same manner as it was for figure 27.

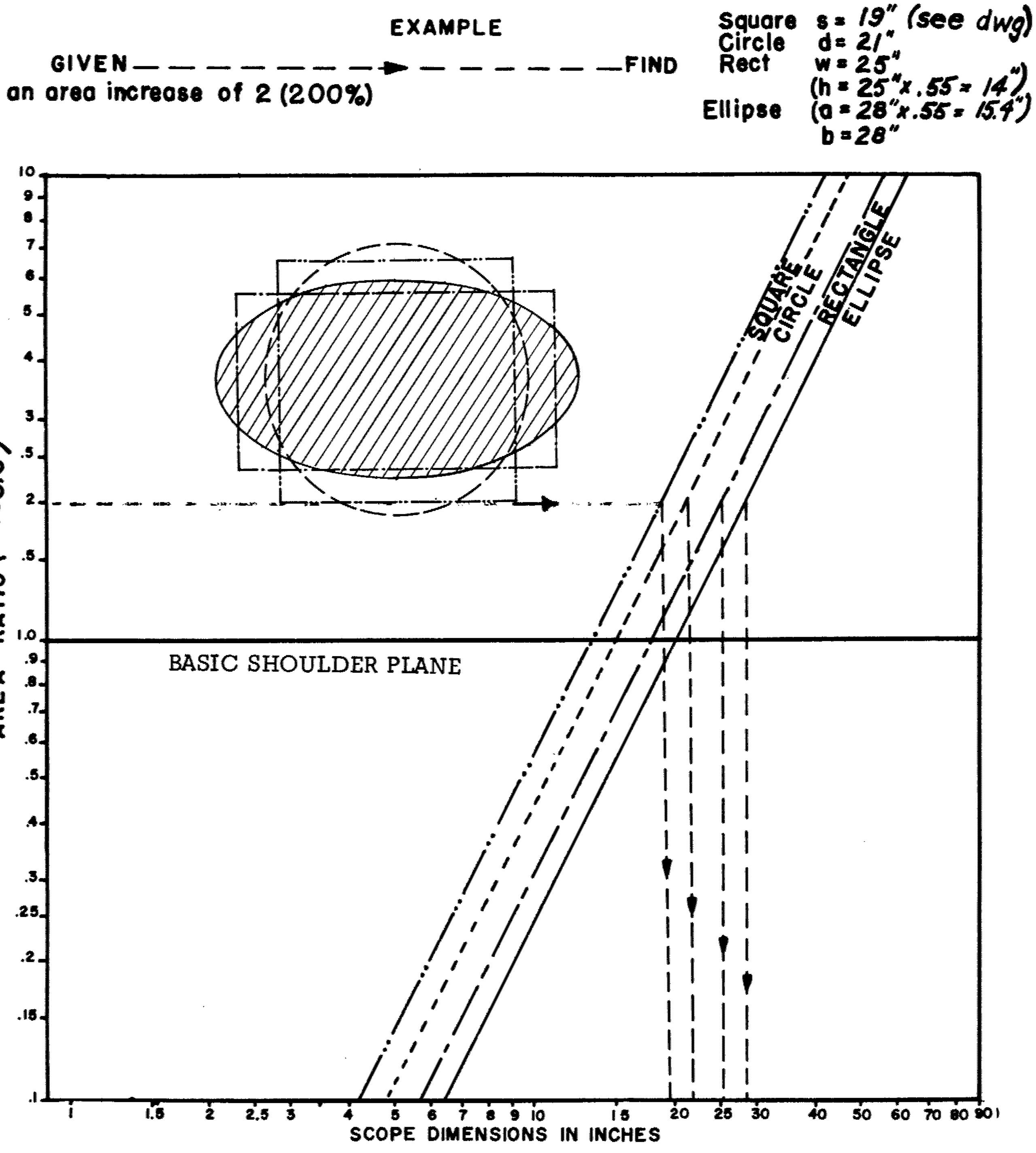


Figure 32. Congruent Expansion of Four Shapes Equated for Area

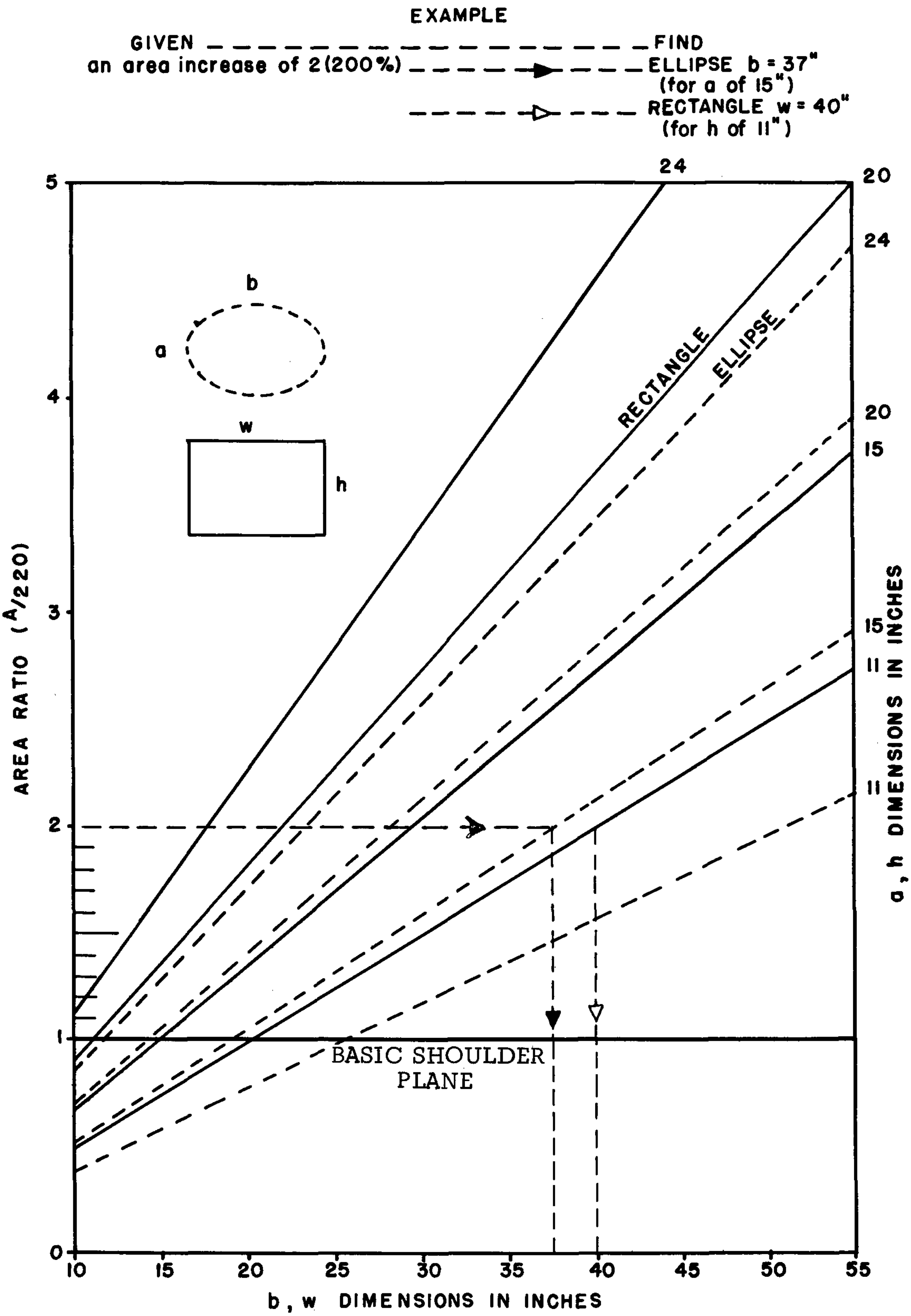


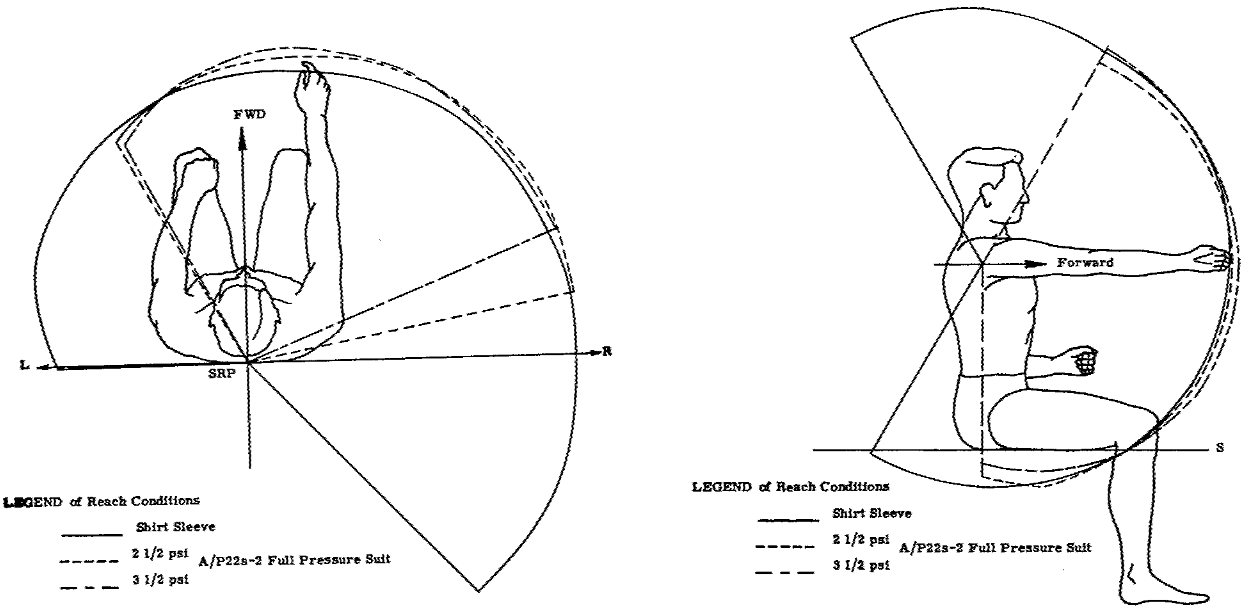
Figure 33. Incongruent Expansion of Four Shapes Equated for Area

APPENDIX IV

REACH ENVELOPES FOR 2.5 AND 3.5 psi INFLATION LEVELS

Kenneth W. Kennedy
Behavioral Sciences Laboratory
Aerospace Medical Research Laboratories

Figure 34 shows the arm-reach envelopes of one subject in a shirt sleeve condition and in the A/P-22S-2 suit, pressurized to 2-1/2 psi and 3-1/2 psi. Figure 34(B) shows a sagittal plane of arm reach envelopes through a point at the right shoulder and 34(A) horizontal plane through a level 25 inches above a seat reference point.



A. Horizontal Plane B. Vertical Sagittal Plane

Figure 34. Reach Envelopes for 2.5 and 3.5 psi Inflation Levels

The envelopes illustrate the following differences in total volume encompassed by the subject's arm reach:

1. Shirt Sleeve = 29.2 cu ft
2. 2 1/2 psi = 15.9 cu ft-54% of No. 1
3. 3 1/2 psi = 14.2 cu ft-48% of No. 1

A 6% volume difference was found between the 2 1/2 and 3 1/2 psi reach envelopes with the A/P-22S-2 full pressure suit. Note that this 6% volume reduction is primarily in the extreme lateral sector of the reach envelope.

The arm-reach capability stated herein is considered by the author to show little difference in mobility in the A/P-22S-2 full pressure suit when the subjects are pressurized to 2-1/2 or 3-1/2 psi although the precise relationship between arm reach and total motion ability are known.

APPENDIX V

DATA ANALYSIS

Anthony Grandillo and William Brockman
Research Institute
University of Dayton

The results of the investigation were tabulated as a factorial experimental design with subjects, suits, gravity, iris clearance, and position-handhold as the five factors. The symbolic notations used in the analysis are as follows:

Nonreplicated Experiments	Replicated Experiments
I (Subjects)	I (Subjects)
I_1 - I_{10}	I_1 - I
J (Clothing and/or Pressure Condition)	
J_1 Unsuited	Same as nonreplicated experiment
J_2 Suited	
K (Gravity Condition)	K
K_1 Zero	Same as nonreplicated experiment
K_2 Lunar	
L (Iris Clearance)	L
L_1 Shoulder width + 1"	Same as nonreplicated experiment
L_2 Shoulder width + 5"	
L_3 Shoulder width + 10"	
M (Position-Handhold)	M
M_1 Head First - Side	Same as nonreplicated experiment
M_2 Head First - Bottom	
M_3 Feet First - Side	
M_4 Feet First - Top	

Nonreplicated Experiment	Replicated Experiment
i = 10 subjects	i = 3 subjects
j = 2 levels of pressures	j = same as nonreplicated experiment
k = 2 levels of gravity	k = same as nonreplicated experiment
l = 3 levels of iris tolerance	l = same as nonreplicated experiment
m = 4 handhold positions	m = same as nonreplicated experiment
	n = number of replicates = 2

T_1 = Lunge Motion Time
T_2 = Time Through Iris
T_3 = Egress Time
T_4 = Total Time = $T_1 + T_2 + T_3$

0^{-2} I = Variance estimate due to subjects
0^{-2} IJ = Variance estimate due to subject x suit interaction etc

A. MEAN TIME SCORES

Except for subjects, pertinent one-way and two-way tables of mean response times for each factor and two-factor combination for the replicated group are charted in the Results Section. The following tables list average (or mean) response times for the nonreplicated group.

T_1 MEAN TIMES

I	1	1.74938
	2	1.05187
	3	0.92895
	4	1.39291
	5	1.64146
	6	1.38978
	7	1.17792
	8	2.45792
	9	1.63208
	10	1.00624

J	1	1.25333
	2	1.63237

K	1	1.56600
	2	1.31970

L

1	2	3
1.47918	1.44944	1.39994

M

1	2	3	4
1.35133	1.30516	1.60750	1-50742

T_1 (Cont'd)

					I					
J	1.54000	0.73833	0.75916	1.36666	1.35625	1.57041	0.73625	2.19833	1.39625	0.87166
	1.95875	1.36541	1.09875	1.41916	1.92666	1.20916	1.61958	2.71750	1.86791	1.14083
					I					
K	1.76583	1.24125	0.93833	1.49666	1.69458	1.49125	1.25958	2.91833	1.76958	1.08458
	1.73291	0.86250	0.91958	1.28916	1.58833	1.28833	1.09625	1.99750	1.49458	0.92791
					I					
	1.71000	1.23687	0.96687	1.32250	1.63250	1.47125	1.21750	2.54000	1.66625	1.02812
L	1.66375	1.02187	0.95750	1.48375	1.65125	1.33937	1.31000	2.54250	1.58812	0.93625
	1.87437	0.89687	0.86250	1.37250	1.64062	1.35875	1.00625	2.29125	1.64187	1.05437
					I					
	1.77500	0.86416	1.03750	1.44083	1.35833	1.34083	0.92500	2.31583	1.46916	0.98666
M	1.72083	0.81666	0.71250	1.28833	1.29166	1.33083	1.50833	2.22916	1.47000	0.68333
	2.10583	1.56333	0.94000	1.70916	2.04916	1.03583	0.93500	2.58666	1.87083	1.27916
	1.39583	0.96333	1.02583	1.13333	1.86666	1.85166	1.34333	2.70000	1.71833	1.07583

		J
K	1.30616	1.82583
	1.20050	1.43891
		J
	1.22612	1.73225
L	1.26537	1.63350
	1.26850	1.53137
		J
	1.13150	1.57116
M	1.16800	1.44233
	1.38383	1.83116
	1.33000	1.68483

T_1 (Cont'd)

		K
	1.64162	1.31675
L	1.61650	1.28237
	1.43987	1.36000

		K
	1.44600	1.25666
M	1.50283	1.10750
	1.74383	1.47116
	1.57133	1.44350

		L	
	1.36875	1.32950	1.35575
M	1.38000	1.30250	1.23300
	1.76550	1.54975	1.50725
	1.40250	1.61600	1.50375

T_2 MEAN TIMES

Nonreplicated Group

I	1	1.27187
	2	1.12167
	3	1.22021
	4	1.40750
	5	1.11000
	6	1.60812
	7	1.72604
	8	2.21167
	9	1.94854
	10	1.05958

J	1	1.25578
	2	1.68124

K	1	1.57287
	2	1.36416

L

1	2	3
1.82937	1.44481	1.13137

T_2 (Cont'd)

						I				
J	1.25041	0.75583	1.25541	1.13750	0.88500	1.57208	1.37541	1.38458	1.80125	1.14041
	1.29333	1.48750	1.18500	1.67750	1.33500	1.64416	2.07666	3.03875	2.09583	0.97875
						I				
K	1.37291	1.27291	1.30750	1.48958	1.17791	1.67750	1.74333	2.51166	2.05791	1.11750
	1.17083	0.97041	1.13291	1.32541	1.04208	1.53875	1.70875	1.91166	1.83916	1.00166
						I				
L	1.57187	1.48125	1.60000	1.52625	1.40437	2.00000	2.21312	2.88375	2.27500	1.33812
	1.13750	1.08562	1.16375	1.53250	0.99687	1.61875	1.66250	2.09625	2.11937	1.03500
	1.10625	0.79812	0.89687	1.16375	0.92875	1.20562	1.30250	1.65500	1.45125	0.80562
						I				
M	1.35833	1.04666	1.40833	1.47833	1.16000	1.61500	1.86083	2.46666	2.15166	1.09333
	1.36000	0.79666	1.07666	1.07416	0.94416	1.00250	1.25250	1.89250	2.32250	1.03250
	1.01166	1.43583	1.36000	1.61500	1.03416	2.30583	2.60416	1.90166	1.69250	1.09250
	1.35750	1.20750	1.03583	1.46250	1.30166	1.50916	1.18666	1.58583	1.62750	1.02000

		J
K	1.36591	1.77983
	1.14566	1.58266
		J
L	1.46912	2.18962
	1.27837	1.61125
	1.01987	1.24287
		J
M	1.36116	1.76666
	1.18383	1.36700
	1.26350	1.94716
	1.21466	1.64416

T_2 Cont'd)

	K	
L	2.03437	1.62437
	1.49425	1.39537
	1.19000	1.07275

	K	
M	1.82583	1.30200
	1.35950	1.19133
	1.62550	1.58516
	1.48066	1.37816

		L	
M	1.87850	1.59950	1.21375
	1.56400	1.30150	0.96075
	2.04300	1.56925	1.20375
	1.83200	1.30900	1.14725

T_3 MEAN TIMES

Nonreplicated Group

I	1	4.07229
	2	3.21958
	3	2.59333
	4	2.91416
	5	2.83166
	6	4.98083
	7	4.38312
	8	4.16646
	9	3.36833
	10	3.59562

J	1	2.98754
	2	4.23754

K	1	4.14967
	2	3.07542

L

1	2	3
3.58644	3.65656	3.59462

M

1	2	3	4
3.80001	3.59400	3.48383	3.57225

T_3 (Cont'd)

I

J	3.83541	2.75458	2.18875	2.07791	2.39541	4.06125	3.79291	3.38875	2.92208	2.45833
	4.30916	3.68458	2.99791	3.75041	3.26791	5.90041	4.97333	4.94416	3.81458	4.73291

I

K	4.91166	4.08083	3.49583	3.34000	2.87958	5.65625	4.97958	4.20041	3.88166	4.07083
	3.23291	2.35833	1.69083	2.48833	2.78375	4.30541	3.78666	4.13250	2.85500	3.12041

I

	4.09625	3.46125	2.61312	3.06812	2.65312	4.82937	4.22437	4.03437	3.27187	3.61250
	3.96375	2.97000	2.87375	2.95062	2.85625	5.26375	4.42625	4.03312	3.68125	3.54687
L	4.15687	3.22750	2.29312	2.72375	2.98562	4.84937	4.49875	4.43187	3.15187	3.62750

I

	4.02750	3.61166	2.36916	3.20000	2.42583	5.15250	4.64250	4.78333	3.47416	4.31416
	3.87833	2.75166	2.57416	2.80083	2.44583	5.10250	4.67083	4.31166	3.37833	4.02583
M	4.40583	3.01166	2.39166	3.03166	3.09666	5.26666	3.90583	3.48250	3.04916	3.19666
	3.97750	3.50333	3.03833	2.62416	3.35833	4.40166	4.31333	4.08833	3.57166	2.84583

J

K	3.47433	4.82500
	2.50075	3.65008

J

	3.04750	4.12537
	2.94925	4.36387
L	2.96587	4.22337

J

	3.43800	4.16216
	3.25366	4.16216
M	2.60500	4.36266
	2.65350	4.49100

T_3 (Cont'd)

	K	
L	3.95575	3.21712
	4.26487	3.04825
	4.22837	2.96087

	K	
M	4.29800	3.30216
	4.24000	2.94800
	3.88066	3.08700
	4.18000	2.96450

	L		
M	3.62650	4.10150	3.67225
	3.54700	3.56675	3.66825
	3.51450	3.43600	3.50100
	3.65775	3.52200	3.53700

T_4 MEAN TIMES ($T_1 + T_2 + T_3$)

Nonreplicated Group

I	1	7.09354
	2	5.39313
	3	4.74250
	4	5.71458
	5	5.58312
	6	7.97875
	7	7.28708
	8	8.83604
	9	6.94896
	10	5.66146

J	1	5.49666
	2	7.55116

K	1	7.28854
	2	5.75929

L

1	2	3
6.89500	6.55081	6.12594

M

1	2	3	4
6.71533	6.17458	6.69667	6.50908

T_4 (Cont'd)

I

J	6.62583	4.24875	4.20333	4.58208	4.63666	7.20375	5.90458	6.97166	6.11958	4.47041
	7.56125	6.53750	5.28166	6.84708	6.52958	8.75375	8.66958	10.70041	7.77833	6.85250

I

K	8.05041	6.59500	5.74166	6.32625	5.75208	8.82500	7.98250	9.63041	7.70916	6.27291
	6.13666	4.19125	3.74333	5.10291	5.41416	7.13250	6.59166	8.04166	6.18875	5.05000

I

L	7.37812	6.17937	5.18000	5.91687	5.69000	8.30062	7.65500	9.45812	7.21312	5.97875
	6.76500	5.07750	4.99500	5.96687	5.50437	8.22187	7.39875	8.67187	7.38875	5.51812
	7.13750	4.92250	4.05250	5.26000	5.55500	7.41375	6.80750	8.37812	6.24500	5.48750

I

M	7.16083	5.52250	4.81500	6.11916	4.94416	8.10833	7.42833	9.56583	7.09500	6.39416
	6.95916	4.36500	4.36333	5.16333	4.68166	7.43583	7.43166	8.43333	7.17083	5.74166
	7.52333	6.01083	4.69166	6.35583	6.18000	8.60833	7.44500	7.97083	6.61250	5.56833
	6.73083	5.67416	5.10000	5.22000	6.52666	7.76250	6.84333	9.37416	6.91750	4.94166

J

K	6.14641	8.43066
	4.84691	6.67166

J

L	5.74275	8.04725
	5.49300	7.60862
	5.25425	6.99762

J

M	5.93066	7.50000
	5.60550	6.74366
	5.25233	8.14100
	5.19816	7.82000

T_4 (Cont'd)

	K	
L	7.63175	6.15825
	7.37562	5.72600
	6.85825	5.39362

	K	
M	7.56983	5.86083
	7.10233	5.24683
	7.25000	6.14333
	7.23200	5.78616

		L	
M	6.87375	7.03050	6.24175
	6.49100	6.17075	5.86200
	7.32300	6.55500	6.21200
	6.89225	6.44700	6.18800

B. 95% CONFIDENCE LIMITS FOR INDIVIDUAL MEANS

Except for the subjects factor, the confidence limits of individual means for main effects are presented in the RESULTS section for the replicated group. The following tables indicate the limits for the main factors of the nonreplicated group and for subjects of the replicated group.

These limits may be used as shown below:

T_1 Nonreplicated
95% Confidence Limits

Subject	Mean	95% Confidence Limits Lower	Upper
1	1.75	1.60	1.90
2	1.05	0.90	1.20
3	0.93	0.78	1.08
4	1.39	1.24	1.54
5	1.64	1.49	1.79
6	1.39	1.24	1.54
7	1.18	1.03	1.33
8	2.46	2.31	2.61
9	1.63	1.48	1.78
10	1.01	0.86	1.16

For example, 95 percent of the time, subject No. 10's true mean response time for 48 trials in this experiment will lie between 0.86 and 1.16 seconds.

T_1

Nonreplicated

95% Confidence Limits

J		95% Confidence Limits		K		95% Confidence Limits	
Suits	Mean	Lower	Upper	Gravity	Mean	Lower	Upper
J_1	1.25	1.18	1.32	K_1	1.57	1.50	1.64
J_2	1.63	1.56	1.70	K_2	1.32	1.25	1.39

L

Iris Tolerance	Mean	95% Confidence Limits Lower	Upper
L_1	1.48	1.40	1.56
L_2	1.45	1.37	1.53
L_3	1.40	1.32	1.48

M

Position-Handholds	Mean	95% Confidence Limits Lower	Upper
M_1	1.35	1.26	1.44
M_2	1.31	1.22	1.40
M_3	1.61	1.52	1.70
M_4	1.51	1.42	1.60

T_2

Nonreplicated

95% Confidence Limits to Means

I

Subjects	Mean	Limits Lower	Upper
1	1.27	1.10	1.44
2	1.12	0.95	1.29
3	1.22	1.05	1.39
4	1.41	1.24	1.58
5	1.11	0.94	1.28
6	1.61	1.44	1.78
7	1.73	1.56	1.90
8	2.21	2.04	2.38
9	1.95	1.78	2.12
10	1.06	0.89	1.23

T_2

Nonreplicated (continued)

95% Confidence Limits

J

Suits	Mean	Limits Lower	Upper
J_1	1.26	1.15	1.34
J_2	1.68	1.60	1.76

K

Gravity	Mean	Limits Lower	Upper
K_1	1.57	1.49	1.65
K_2	1.36	1.28	1.44

L

Iris Clearance	Mean	Limits Lower	Upper
L_1	1.83	1.74	1.92
L_2	1.44	1.35	1.53
L_3	1.13	1.04	1.22

$$S_{\bar{y}}^2 = \frac{0.35262}{160} = 0.0022039$$

$$S_{\bar{y}} = 0.0469$$

$$tS_{\bar{y}} = 1.96(0.0469) = 0.09$$

M

Position-Handhold	Mean	Limits Lower	Upper
M_1	1.56	1.45	1.67
M_2	1.27	1.16	1.38
M_3	1.60	1.49	1.71
M_4	1.42	1.31	1.53

T_3
Nonreplicated

95% Confidence Limits for Means

I

Subjects	Mean	Limits Lower	Upper
1	4.07	3.65	4.49
2	3.22	2.80	3.64
3	2.59	2.17	3.01
4	2.91	2.49	3.33
5	2.83	2.41	3.25
6	4.98	4.56	5.40
7	4.38	3.96	4.80
8	4.17	3.75	4.59
9	3.37	2.95	3.79
10	3.60	3.18	4.02

J

Suits	Mean	Limits Lower	Upper
J_1	2.99	2.80	3.18
J_2	4.24	4.05	4.43

K

Gravity	Mean	Limits Lower	Upper
K_1	4.15	3.96	4.34
K_2	3.08	2.89	3.27

L

Iris Tolerance	Mean	Limits Lower	Upper
L_1	3.59	3.36	3.82
L_2	3.66	3.43	3.89
L_3	3.59	3.36	3.82

T_3

Nonreplicated (continued)

95% Confidence Limits for Means

M

Position-Handhold	Mean	Limits Lower	Upper
M_1	3.80	3.54	4.06
M_2	3.59	3.33	3.85
M_3	3.48	3.22	3.74
M_4	3.57	3.31	3.83

T_4 Nonreplicated

95% Confidence Limits for Means

I

Subjects	Means	Limits Lower	Upper
1	7.09	6.59	7.59
2	5.39	4.89	5.89
3	4.74	4.24	5.24
4	5.71	5.21	6.21
5	5.58	5.08	6.08
6	7.98	7.48	8.48
7	7.29	6.79	7.79
8	8.84	8.34	9.34
9	6.95	6.45	7.45
10	5.66	5.16	6.16

J

Suits	Mean	Limits Lower	Upper
J_1	5.50	5.28	5.72
J_2	7.55	7.33	7.77

K

Gravity	Mean	Limits Lower	Upper
K_1	7.29	7.04	7.51
K_2	5.76	5.54	5.98

$$S^2_{\bar{y}} = \frac{3.108}{240} = 0.01295 \quad S_{\bar{y}} = 0.1138$$

$$t\ S_{\bar{y}} = 0.22$$

T_4

Nonreplicated (continued)

95% Confidence Limits for Means

M

$S_{\bar{y}}^2 = \frac{3.108}{120} = 0.0259$

$S_{\bar{y}} = 0.1609$

$t\,S_{\bar{y}} = 0.32$

Position-Handholds	Mean	Limits Lower	Limits Upper
M_1	6.72	6.40	7.04
M_2	6.17	5.85	6.49
M_3	6.70	6.38	7.02
M_4	6.51	6.19	6.83

Iris Tolerance	Mean	Limits Lower	Limits Upper
L_1	6.90	6.63	7.17
L_2	6.55	6.28	6.82
L_3	6.13	5.86	6.40

T_1 (With Replication)

95% Confidence Limits for Means

I

Subjects	Mean	95% Confidence Limits Lower	95% Confidence Limits Upper
1	1.43	1.32	1.54
2	0.95	0.84	1.06
3	1.32	1.21	1.43

C. ANALYSIS OF VARIANCE

The analysis of variance tables indicate whether any significant differences exist among mean times within each factor and whether any interaction among these factors can be judged significant. The asterisks indicate, at the 95% confidence level, which source of variation is significant. For example M* indicates that there is a significant difference among mean times due to position-handhold conditions. Normally, where significance does occur the differences between mean times are more pronounced.

The analysis of variance with its associated components of variance and F tests are based upon the fact that all factors are fixed with the exception of subjects which is assumed to be random.

Although many interactions were found to be significant in the nonreplicated experiment, they were not shown not to exist in the replicated experiment. More reliable conclusions with respect to the existence of the interactions should be based on the replicated experiment and this is why the data presented in the Results section presents only the replicated data.

T_1 Nonreplicated

Analysis of Variance Table

Source of Variation	Sum of Squares	df	Mean Squares	Fc	F.05
I*	90.36653	9	10.04073	43.23*	2.05
J*	17.24069	1	17.24069	12.31*	5.12
K*	7.27914	1	7.27914	8.97*	5.12
L	0.51285	2	0.25642	1.10	3.17
M*	7.03325	3	2.34442	3.02*	2.96
IJ*	12.60652	9	1.40072	6.03*	2.05
IK*	7.30313	9	0.81146	3.49*	2.05
IL	2.93216	18	0.16290	<1	
IM*	20.98290	27	0.77714	3.45*	1.70
JK	2.37306	1	2.37306	3.63	5.12
JL	1.19058	2	0.59529	2.56	3.17
JM	0.59669	3	0.19890	<1	
KL*	1.66339	2	0.83169	3.58	3.17
KM	1.20558	3	0.40186	<1	
LM	2.39816	6	0.39969	1.72	2.27
IJK*	5.88963	9	0.65440	2.817*	2.05
IJL	3.47658	18	0.19314	<1	
IJM*	12.91498	27	0.47833	2.06*	1.70
IKL	6.30856	18	0.35048	1.51	1.80
IKM*	15.46238	27	0.57268	2.46*	1.70
ILM	17.54860	54	0.32497	1.40	1.58
JKL*	2.40129	2	1.20064	5.17*	3.17
JKM	0.24211	3	0.08070	<1	
JLM	0.85424	6	0.14237	<1	
KLM	1.96768	6	0.32795	1.41	2.27
IJKL	5.61465	18	0.31193	1.34	1.80
IJKM	8.68115	27	0.32152	1.38	1.70
IJLM	14.00353	54	0.25932	1.12	1.58
IKLM	12.11724	54	0.22439	<1	
JKLM	0.78386	6	0.13064	<1	
Residual	12.54337	54	0.23228		
Total	296.49446	479			

*Significant @ 95% confidence level.

T_2 Nonreplicated

Analysis of Variance Table

Source of Variation	Sum of Squares	df	Mean Square	Fc	F.05
I*	66.65372	9	7.40597	31.83*	2.05
J*	21.72176	1	21.72176	6.33*	5.12
K*	5.22709	1	5.22709	22.46*	4.02
L*	39.11120	2	19.55560	84.04*	3.17
M*	7.99636	3	2.66545	2.06	2.96
IJ*	30.86665	9	3.42963	14.74*	2.05
IK	2.57221	9	0.28580	1.23	2.05
IL	6.98776	18	0.38821	1.67	1.80
IM*	34.92682	27	1.29359	5.56*	1.70
JK	.01600	1	0.01600	<1	
JL*	5.46445	2	2.73223	7.69*	3.55
JM*	3.77376	3	1.25792	3.04*	2.95
KL	2.43787	2	1.21894	5.24*	3.17
KM*	4.21734	3	1.40578	6.04*	2.78
LM	1.53425	6	0.25571	1.10	2.27
IJK	2.03471	9	0.22608	<1	
IJL	6.39841	18	0.35547	1.53	1.80
IJM*	11.18846	27	0.41439	1.78*	1.70
IKL	6.11867	18	0.33993	1.46	1.80
IKM	6.86553	27	0.25428	1.09	1.70
ILM	16.96229	54	0.31412	1.35	1.58
JKL*	1.72738	2	0.86369	3.71*	3.17
JKM*	2.37661	3	0.79220	3.40*	2.78
JLM	1.33845	6	0.22307	<1	
KLM	4.51376	6	0.75229	2.03	2.27
IJKL	5.06030	18	0.28113	1.21	1.80
IJKM	9.89453	27	0.36646	1.58	1.70
IJLM	18.69567	54	0.34622	1.49	1.58
IKLM*	20.00287	54	0.37042	1.592*	1.575
JKLM*	3.24877	6	0.54146	2.33*	2.27
R (Residual)	12.56573	54	0.23270		
Total	362.49935	479			

* Significant @ 95% confidence level

T_3 Nonreplicated

Analysis of Variance Table

Source of Variation	Sum of Squares	df	Mean Square	Fc	F.05
I*	256.07200	9	28.45244	15.12*	2.05
J*	187.49984	1	187.49984	49.461*	5.12
K*	138.48140	1	138.48140	30.13*	5.12
L	0.47044	2	0.23522	< 1	
M	6.44459	3	2.14820	1.14	2.78
IJ	34.11771	9	3.79086	2.02	2.05
IK*	41.36864	9	4.59652	2.44*	2.05
IL	13.14573	18	.73032	< 1	
IM	54.70892	27	2.02626	1.08	1.70
JK	1.21624	1	1.21624	<1	
JL	2.27152	2	1.13576	<1	
JM*	36.10582	3	12.03527	6.40*	2.78
KL	6.81054	2	3.40527	1.81	3.17
KM	4.56743	3	1.52248	<1	
LM	5.94517	6	0.99086	<1	
IJK	25.79298	9	2.86589	1.52	2.05
IJL	42.65528	18	2.36974	1.26	1.80
IJM	49.97903	27	1.85108	<1	
IKL	18.15221	18	1.00846	<1	
IKM	74.28392	27	2.75126	1.46	1.70
ILM	128.15094	54	2.37317	1.26	1.58
JKL	7.33247	2	3.66623	1.95	3.17
JKM	8.71169	3	2.90390	1.54	2.78
JLM	8.50646	6	1.41774	<1	
KLM*	34.15989	6	5.69332	3.03*	2.18
IJKL	58.53851	18	3.25214	1.73	1.80
IJKM	71.75115	27	2.65745	1.412	1.70
IJLM	90.43524	54	1.67473	<1	
IKLM	135.29562	54	2.50547	1.33	1.58
JKLM	20.45319	6	3.40886	1.81	2.27
R (Residual)	101.59424	54	1.88137		
Total	1665.01871	479			

* Signigicant @ 95% confidence level

T_4 Nonreplicated

Analysis of Variance Table for T_4

Source of Variation	Sum of Squares	df	Mean Square	Fc	F. 05
I*	733. 73263	9	81. 52585	29. 68*	2. 05
J*	506. 51599	1	506. 51599	61. 70*	5. 12
K*	280. 63232	1	280. 63232	102. 15*	4. 02
L*	47. 49015	2	23. 74508	8. 64*	3. 17
M	22. 64839	3	22. 64839	2. 75	2. 78
IJ*	73. 88351	9	8. 20928	2. 99*	2. 05
IK	33. 46553	9	3. 71839	1. 35	2. 05
IL	25. 86494	18	1. 43694	<1	
IM	94. 33436	27	3. 49387	1. 27	1. 70
JK	6. 33467	1	6. 33467	1. 90	5. 12
JL	6. 52178	2	3. 26089	1. 19	3. 17
JM*	62. 78305	3	20. 92768	7. 62*	2. 78
KL	0. 87127	2	0. 43563	<1	
KM	9. 72884	3	3. 24295	1. 18	2. 78
LM	10. 41305	6	1. 73551	<1	
IJK	30. 04356	9	3. 33817	1. 21	2. 05
IJL	61. 05026	18	3. 39168	1. 23	1. 80
IJM	70. 13046	27	2. 59742	<1	
IKL	28. 31662	18	1. 57315	<	
IKM	116. 41867	27	4. 31180	1. 57	1. 70
ILM	179. 38415	54	3. 32193	1. 21	1. 58
JKL	0. 98441	2	0. 49220	<1	
JKM	22. 26795	3	7. 42265	2. 70	2. 78
JLM	9. 33752	6	1. 55625	<1	
KLM*	40. 15098	6	6. 69183	2. 44*	2. 27
IJKL	71. 86357	18	3. 99242	1. 45	1. 80
IJKM	111. 23840	27	4. 11994	1. 50	1. 70
IJLM	121. 21143	54	2. 24466	<1	
IKLM	189. 37398	54	3. 50693	1. 28	1. 58
JKLM	22. 22580	6	3. 70430	1. 35	2. 27
R (Residual)	148. 35477	54	2. 74731		
Total	3137. 57288	479			

* Significant @ 95% confidence level

T_1 (Replicated)

Analysis of Variance

Source of Variation	Sum of Squares	df	Mean Squares	Fc	F.05
I*	6.37259	2	3.18629	8.15*	3.06
J*	8.30960	1	8.30960	21.26*	3.91
K*	2.79267	1	2.79267	7.14*	3.91
L	0.02854	2	0.01427	<1	
M*	7.81898	3	2.60633	6.67*	2.67
IJ	0.60668	2	0.30334	<1	
IK	0.35269	2	0.17634	<1	
IL	0.75919	4	0.18980	<1	
IM	2.36672	6	0.39445	1.01	2.16
JK	0.48347	1	0.48347	1.24	3.91
JL	0.06454	2	0.03227	<1	
JM	2.50390	3	0.83463	2.14	2.67
KL	0.03759	2	0.01879	<1	
KM	0.92566	3	0.30855	<1	
LM	2.71526	6	0.45254	1.16	2.16
IJK	0.86125	2	0.43063	1.10	3.06
IJL	1.88111	4	0.47028	1.20	2.43
IJM	2.81130	6	0.46855	1.20	2.16
IKL	1.04599	4	0.26150	<1	
IKM	0.91776	6	0.15296	<1	
ILM	1.55767	12	0.12981	<1	
JKL	0.43701	2	0.21850	<1	
JKM	0.20089	3	0.06696	<1	
JLM	1.26753	6	0.21125	<1	
KLM	0.43608	6	0.07268	<1	
IJKL	1.04708	4	0.26177	<1	
IJKM	0.20735	6	0.03456	<1	
IJLM	2.96794	12	0.24733	<1	
IKLM	1.93481	12	0.16123	<1	
JKLM	0.82822	6	0.13804	<1	
IJKLM	2.41283	12	0.20107	<1	
Residual	56.29027	144	0.39090		
Total	113.24317	287			

* Significant @ 95% confidence level

T_2 (Replicated)

Analysis of Variance

Source of Variation	Sum of Squares	df	Mean Square	Fc	F.05
I*	1.79708	2	0.89854	3.68*	3.06
J*	7.02812	1	7.02812	28.77*	3.91
K*	2.55568	1	2.55568	10.46*	3.91
L*	12.76896	2	6.38448	26.13*	3.06
M	0.76517	3	0.25506	1.04	2.67
IJ	1.40237	2	0.70119	2.87	3.06
IK	0.20327	2	0.10163	<1	
IL	0.69339	4	0.17335	<1	
IM	2.08966	6	0.34828	1.42	2.16
JK	0.39828	1	0.39828	1.63	3.91
JL	1.34402	2	0.67201	2.75	3.06
JM	0.80595	3	0.26865	1.10	2.67
KL	0.41827	2	0.20914	<1	
KM	1.57769	3	0.52590	2.15	2.67
LM	0.92464	6	0.15411	<1	
IJK	0.00781	2	0.00390	<1	
JL	0.63584	4	0.15896	<1	
IJM	1.69952	6	0.28325	1.16	2.16
IKL	0.63475	4	0.15869	<1	
IKM	2.45943	6	0.40991	1.68	2.16
ILM	1.36638	12	0.11387	<1	
JKL	0.12617	2	0.06309	<1	
JKM	0.73258	3	0.24419	<1	
JLM	1.02370	6	0.17062	<1	
KLM	1.96547	6	0.32758	1.34	2.16
IJKL	1.78364	4	0.44591	1.82	2.43
IJKM	1.65854	6	0.27642	1.13	2.16
IJLM	1.88113	12	0.15676	<1	
IKLM	2.34174	12	0.19515	<1	
JKLM	1.70708	6	0.28451	1.97	3.00
IJKLM	1.73063	12	0.14422	<1	
Residual	35.18173	144	0.24432		
Total	91.70871	287			

* Significant @ 95% confidence level

T_3 (Replicated)

Analysis of Variance Table for T_3

Source of Variation	Sum of Squares	df	Mean Square	Fc	F.05
I*	31.61554	2	15.80777	5.60*	3.91
J*	47.21489	1	47.21489	16.73*	3.91
K*	105.79061	1	105.79061	37.49*	3.91
L	0.79145	2	0.39573	<	
M	3.35081	3	1.11694	<1	
IJ	4.35940	2	2.17970	<1	
IK	11.79458	2	5.89729	2.09	3.06
IL	5.48418	4	1.37104	<1	
IM	11.83721	6	1.97287	<1	
JK	4.36851	1	4.36851	1.55	3.91
JL	7.32872	2	3.66436	1.30	3.06
JM	18.49865	3	6.16622	2.18	2.67
KL*	12.40061	2	6.20030	3.40*	3.06
KM	8.67747	3	2.89249	1.02	3.06
LM	7.80156	6	1.30026	<1	
IJK	1.39753	2	0.69877	<1	
IJL	1.02295	4	0.25574	<1	
IJM	3.33172	6	0.55529	<1	
IKL	5.37261	4	1.34315	<1	
IKM	11.60182	6	1.93364	<1	
ILM	16.28540	12	1.35712	<1	
JKL	8.42432	2	4.21216	1.49	3.06
JKM	1.50714	3	0.50238	<1	
JLM	6.87609	6	1.14601	<1	
KLM	8.33523	6	1.38920	<1	
IJKL	3.40405	4	0.85101	<1	
IJKM	12.15565	6	2.02594	<1	
IJLM	11.11305	12	0.92609	<1	
IKLM	28.48118	12	2.37343	<1	
JKLM	20.02110	6	3.33685	1.77	3.00
IJKLM	22.59774	12	1.88315	<1	
Residual	406.31219	144	2.82161		
Total	849.55390	287			

* Significant @ 95% confidence level

T_4 (Replicated)

Analysis of Variance Table for T_4

Source of Variation	Sum of Squares	df	Mean Square	Fc	F.05
I*	63.79561	2	31.89780	6.81*	3.01
J*	152.38214	1	152.38214	32.51*	3.91
K*	182.10269	1	182.10269	38.86*	3.91
L	16.62119	2	8.31059	1.77	3.06
M	20.30181	3	6.76727	1.44	2.67
IJ	4.98650	2	2.49325	<1	
IK	6.09828	2	3.04914	<1	
IL	6.80068	4	1.70017	<1	
IM	17.70763	6	2.95127	<1	
JK	11.28525	1	11.28525	2.41	3.91
JL	7.85864	2	3.92932	<1	
JM	36.10864	3	12.03621	2.57	2.67
KL	8.08678	2	4.04339	<1	
KM	11.77885	3	3.92628	<1	
LM	15.16152	6	2.52692	<1	
IJK	0.63177	2	0.31588	<1	
IJL	4.87847	4	1.21962	<1	
IJM	5.22060	6	0.87010	<1	
IKL	9.36061	4	2.34015	<1	
IKM	11.32284	6	1.88714	<1	
ILM	19.99634	12	1.66636	<1	
JKL	5.63385	2	2.81692	<1	
JKM	2.27580	3	0.75860	<1	
JLM	6.22405	6	1.03734	<1	
KLM	12.10316	6	2.01719	<1	
IJKL	11.08186	4	2.77047	<1	
IJKM	18.96410	6	3.16068	<1	
IJLM	16.85468	12	1.40456	<1	
IKLM	39.82043	12	3.31837	<1	
JKLM	23.68732	6	3.94789	<1	
IJKLM	34.69620	12	2.89135	<1	
Residual	674.89417	144	4.68677	—	
Total	1458.72243	287			

* Significant @ 95% confidence level

D. HOMOGENEITY OF VARIANCE

Bartlett's* Test of Homogeneity of Variance was used to treat the replicated experiment. In the replicated experiment (3 subjects replicated twice), 144 within cell variances for each T_i time score were tested for equality. It can be concluded that T_1, T_3 and T_4 within cell variances are equal. T_2 time within cell variances were found to be slightly heterogeneous.

TEST FOR HOMOGENEITY OF VARIANCES FOR REPLICATED DATA

Formulae:

$$*M = (N-K)\ln Sp^2 - \Sigma[(ni-1)\ln Si^2$$

where ni = # of replicates = 2
and N = Total number of samples = 288
K = " " of variables = 144

$$*M = 144 \ln Sp^2 - \sum_{i=1}^{i=144} \ln Si^2$$

$$\text{where } Si^2 = \frac{(X_{1i} - X_{2i})^2}{2}$$

$$X_{1i} = \text{1st trial}$$

$$X_{2i} = \text{2nd } "$$

$$*Sp^2 = \frac{\Sigma\,(ni-1)\,Si^2}{N-K} = \frac{\Sigma\,Si^2}{144}$$

$$*A = \frac{1}{3(K-1)}\left[\sum\left(\frac{1}{ni-1}\right) - \frac{1}{N-K}\right] = \frac{1}{3(143)}\left[144 - \frac{1}{144}\right]$$

$$= \frac{1}{3(143)}\left[\frac{144^2-1}{144}\right]$$

$$= \frac{1}{3(143)}\;\frac{(144+1)(144-1)}{144}$$

$$= \frac{145}{3(144)} = \frac{145}{432} =$$

$$A = 0.335648$$

$$A^2 = 0.11266$$

$$*V_1 = K-1 = 143$$

$$*V_2 = \frac{K+1}{A^2} = \frac{145}{0.11266} = 1287.1$$

$$*b = \frac{V_2}{1-A+(^2/V_2)} = \frac{1287.1}{1-0.3356+(^2/1287.1)} = 1932.582$$

$$*F = \frac{V_2 M}{V_1(b-M)}$$

*pg. 179 Dixon & Massey's "Introduction to Statistical Analysis"

$T_1 \quad F = \dfrac{1287.1(249.586)}{143(1932.582-249.586)} = \dfrac{321{,}242.14}{240{,}668.43} = 1.33$

$T_2 \quad F = \dfrac{128.7(265.742)}{143(1932.582-265.742)} = \dfrac{342{,}036.53}{238{,}358.12} = 1.43$

$T_3 \quad F = \dfrac{1287.1(241.455)}{143(1932.582-241.455)} = \dfrac{310{,}776.73}{241{,}831.16} = 1.28$

$T_4 \quad F = \dfrac{1287.1(233.890)}{143(1932.582-233.890)} = \dfrac{301{,}039.82}{242{,}912.96} = 1.24$

		M
	T_1	249.586
$F_{.05} = 1.34$	T_2	265.742
$F_{.025} = 1.42$	T_3	241.455
$F_{.01} = 1.51$	T_4	233.890

T_1, T_3, and T_4 have the homogeneity criteria satisfied.
T_2 times are slightly heterogeneous.

E. TIME SCORE CORRELATIONS

The following table lists product moment correlations between time scores T-1, T-2, T-3 and T-4 for the replicated group (N=144).

	T1	T2	T3	T4
T1		0.27	0.24	0.58
T2			0.19	0.56
T3				0.87

The three motion scores (T1, T2 and T3) were positively correlated with each other and the total score. The authors presumed that subjects might sacrifice lunge time (T1) to better position themselves for a faster egress time (T2); however, the scatterplots failed to indicate any inverse relationships. The three motion correlations (indicated within dotted line) suggest that the measures were relatively independent, ie, the authors were not measuring the same thing three times.

APPENDIX VI

SUBJECTS' ANTHROPOMETRIC DATA

		1	2	3	4	5	6	7	8	9	10	Range	Mean
Height	CM	180.0	166.7	188.6	183.4	177.3	170.2	178.44	181.2	185.50	182.9	166.70-188.60	179.42
	IN	70.87	65.63	74.24	72.2	69.7	67.01	70.25	71.35	73	72	65.63- 74.25	70.60
	%-ile	77	8	98	90	60	20	67	81	94	87		
Weight	LBS	186.0	157.0	189.0	162	162	175.5	145	168	171	185.5	145.00-189.00	170.10
	%-ile	85	41	85.5	50	50	74	20	62	66	85		
Shoulder Breadth	CM	48.8	45.5	50.3	49.6	49.0	46.5	43.69	46.1	48.0	48.7	43.69- 50.30	47.62
	IN	19.21	17.21	19.80	19.5	19.25	18.31	17.2	18.1	18.9	19.15	17.20- 19.80	18.75
	%-ile	92	52	98	96	92	67	22	60	86	90		
Shoulder Circumference	CM	117.5	114.6	124.1	116.08	120.2	115.6	115.06	112.52	116.3	116.5	112.52-124.10	116.83
	IN	46.25	42.12	48.86	45.7	47.3	45.51	45.3	44.3	45.8	45.8	44.30- 48.86	46.00
	%-ile	67	50	92	60	80	55	53	35	60	61		
Chest Depth	CM	24.8	24.0	26.3	21.8	25.5	26.2	25.15	23.9	23.7	24.1	21.80- 26.30	24.55
	IN	9.76	9.45	10.35	8.7	10.01	10.31	9.9	9.4	9.3	9.5	8.70- 10.35	9.66
	%-ile	81	71	95	30	90	94	85	70	65	72		
Cervical Height	CM	154.3	140.2	161.9	158.5	150.0	145.1	153.54	155.8	159.6	159.1	140.20-161.90	153.80
	IN	60.75	55.20	63.74	62.4	59.1	57.13	60.45	61.35	62.9	62.7	55.20- 63.74	60.55
	%-ile	77	5	97	92	49	20	72	82	95	94		
Hip Breadth-Standing	CM	38.7	32.8	37.6	35.7	34.6	35.6	33.78	35.1	36.4	34.6	32.80- 38.70	35.49
	IN	15.24	12.91	14.80	14.05	13.6	14.02	13.3	13.85	14.35	13.6	12-91- 15.24	13.97
	%-ile	98	35	97	96	70	86	55	80	93	74		
Buttock Depth	CM	26.0	24.5	25.4	24.51	23.6	27.2	22.61	23.9	23.7	26.0	22.61- 27.20	24.74
	IN	10.24	9.65	10.00	9.65	9.3	10.71	8.9	9.4	9.36	10.25	8.90- 10.71	9.74
	%-ile	95	83	91	82	72	99	55	75	75	95		
Buttock Circumference	CM	106.0	94.0	102.1	97.03	94.0	104.0	93.73	96.77	101.3	104.0	93.73-106.00	99.32
	IN	41.73	37.01	40.20	38.2	37.0	40.94	36.9	38.1	39.8	40.8	36.90- 41.73	39.10
	%-ile	95	38	85	59	40	90	36	55	81	90		
Trochanteric Height	CM	92.1	83.7	97.2	96.4	88.4	88.5	94.11	96.2	99.4	92.5	83.70- 99.40	92.85
	IN	36.26	32.95	38.27	37.95	34.8	34.84	37.05	38.0	39.13	36.5	32.95- 39.13	36.56
	%-ile*												
Sitting Height	CM	95.1	89.3	99.4	94.9	93.98	90.5	91.06	94.49	91.7	95.3	89.30- 99.40	93.57
	IN	37.44	35.16	39-13	37.4	37.0	35.63	35.85	37.2	36.1	37.55	35.16- 39.13	36.84
	%-ile	87	27	99+	86	80	40	45	84	55	94		
Shoulder-Elbow Length	CM	38.3	34.3	39.0	37.34	37.85	35.9	35.94	39.75	38.8	37.5	34.30- 39.75	37.47
	IN	15.08	13.50	15.35	14.7	14.9	14.13	14.5	15.65	15.3	14.75	13.50- 15.65	14.75
	%-ile	85	12	95	70	80	39	60	97	92	72		
Forearm-Hand Length	CM	48.1	45.4	51.5	50.16	48.01	47.3	49.28	48.77	49.7	50.1	45.50- 51.50	48.83
	IN	18.94	17.87	20.28	19.75	18.9	18.62	19.4	19.2	19.6	19.7	17.87- 20.28	19.22
	%-ile	52	11	95	86	50	37	75	65	80	85		
Knee Height, Sitting	CM	54.1	50.4	57.3	57.15	53-59	51.9	55.25	56.6	58.9	58.1	50.40- 58.90	55.33
	IN	21.30	19.84	22.56	22.5	21.1	20.43	21.75	22.3	23.2	22.9	19.84- 23.20	21.78
	%-ile	35	3	80	80	27	10	52	72	94	88		
Butt-Knee Length	CM	63.1	57.2	63.5	61.6	60.05	60.3	61.47	63.0	63.6	62.2	57.20- 63.60	61.60
	IN	24.84	22.52	25.00	24.25	23.65	23.74	24.2	24.8	25.1	24.5	22.52- 25.10	24.25
	%-ile	87	15	90	72	50	55	70	86	91	80		
Max. Br; Arms Overhead	CM	44.6	47.1	53.7	47.5	42.7	52.0	40.39	35.94	40.05	40.0	35.94- 53.70	44.48
	IN	17.56	18.54	21.14	18.7	16.85	20.47	15.9	14.15	15.8	15.8	14.15- 21.14	17.51
	%-ile*												

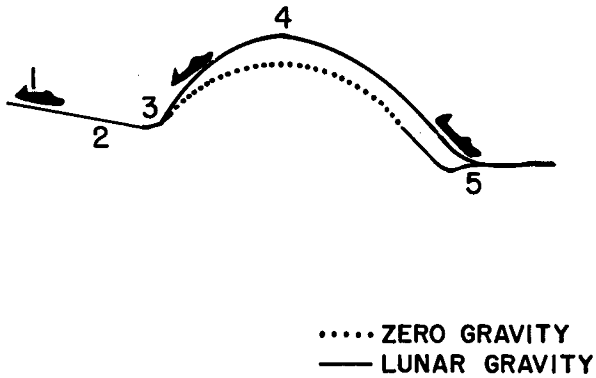
* Information not collected during 1950 Survey, as published in WADC TR 52-321 (Ref 20)

APPENDIX VII

The Lunar Gravity Maneuver

B. C. Dixon
Lear-Siegler Service, Inc.

The ever-changing requirements in space oriented research have necessitated that the aircraft used for zero-G maneuvers also simulate lunar gravity (0.17 earth gravity). The maneuver for lunar gravity is accomplished in the same general manner as a zero-G parabola. The following sketch illustrates the five phases of the lunar- and zero-gravity maneuvers as flown in a C-131B aircraft.



During phase 1, the aircraft is maintained in level flight while preparing to enter the maneuver. At phase 2, the aircraft is placed in a 12° dive and military thrust power applied until 250 knots indicated airspeed is attained. At this point, phase 3, the aircraft is maintained at 2.5 normal acceleration in a climb until a 35° pitch up attitude is reached. Beginning phase 4, the stick is pushed forward to push the nose of the airplane down. By controlling the pitch attitude of the aircraft, the desired gravity level is maintained until a pitch down attitude of 35° is reached. Phase 4 is that portion of the maneuver in which lunar gravity and zero-G maneuvers differ. During this phase, the aircraft will float higher and longer during a lunar gravity maneuver than in a zero-G maneuver. The selected gravity level (zero or lunar) to be flown is displayed to the pilot on the horizontal bar of a Model 4055D Attitude Director Indicator. By keeping the horizontal bar at center, the selected gravity level is maintained throughout phase 4 of the maneuver, which is approximately 15 seconds duration. Accuracy of +0.005 G can be maintained for 8 to 12 seconds with the remaining 3 to 7 seconds +0.025 G accuracy. Phase 5 is the pull-out phase during which the aircraft returns to level flight with a 2.5 normal acceleration pull up.

Security Classification

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, Ohio	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
	2b GROUP N/A	
3. REPORT TITLE MOBILITY OF PRESSURE-SUITED SUBJECTS UNDER WEIGHTLESS AND LUNAR GRAVITY CONDITIONS		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report June 1961-June 1962		
5. AUTHOR(S) (Last name, first name, initial) Simons, John C., Major, USAF, Walk, Dieter E., Sears, Charles W., M/Sgt, USAF		
6. REPORT DATE August 1965	7a. TOTAL NO. OF PAGES 95	7b. NO. OF REFS none
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) AMRL-TR-65-65	
b. PROJECT NO 7184		
c. Task No. 718405 718408	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10. AVAILABILITY/LIMITATION NOTICES Distribution of this document is unlimited		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, Ohio	

13. ABSTRACT

Problems of moving through hatchways under zero and lunar gravityconditons, and related design problems of hatch size and shape, were investigated in flight. Subjects were timed and photographed as they accomplished various motions during weightless and lunar-gravity maneuvers of a large cabin aircraft. Performance data are presented for various combinations of clothing, gravity and body-position conditions. Time and contact data are presented for the egress motion as it is influenced by changes in the exit area. Orientation problems and maneuvering techniques, as influenced by area and volume restrictions, are disucssed. Motions of pressure- suited subjects generally required 30% more time than corresponding motions of unsuited subjects. Most motions required 35% more time during zero G than during lunar G. No significant differences in egress times were found among four body-positions. Compared with 1 inch of exit clearance, 5 inches of clearance improved egress time by approximately 6%. Accuracy, rather than time of motion, appeared to be a more sensitive measure of operator performance for the egress task. A 95th percentile shoulder plane with a 19.4-inch major axis is proposed as a basic egress reference.

DD FORM 1 JAN 64 1473

AF-WP-B-AUG 64 400

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Weightlessness Human engineering Pressure suits Behavior (Motion) Maneuverability Gravity Space flight Body						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.